RANCANG BANGUN PEMBANGKIT LISTRIK HIBRIDA MENGGUNAKAN KINCIR ANGIN SUMBU VERTIKAL SAVONIUS DAN PANEL SEL SURYA SKALA KECIL

SKRIPSI

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JURUSAN TEKNIK ELEKTRO S-1

KONSENTRASI TEKNIK ENERGI LISTRIK

FAKULTAS TEKNOLOGI INDUSTRI

INSTITUT TEKNOLOGI NASIONAL MALANG

2017

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LEMBAR PERSETUJUAN

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ABSTRAK

Abstrak - Perkembangan teknologi terutama di bidang tenaga listrik berkembang sangat pesat dan semakin meningkat kebutuhan energi listrik dengan seiring bertambahnya jumlah perangkat yang membutuhkan energi listrik, tetapi pada saat ini kebutuhan energi listrik dipenuhi dengan energi listrik yang dibangkitkan dari bahan bakar fosil yang jumlahnya semakin sedikit dan suatu saat nanti akan habis dan tidak dapat di perbaharui, dari krisisnya energi muncul topik yang sering di bahas yakni bagaimana memanfaatkan sumber energi alternatif sebagai pembangkit listrik.

Pada makalah ini telah direalisasikan suatu pembangkit hibrida dengan memanfaatkan sumber energi alternatif seperti energi angin dan energi matahari yang dapat di manfaatkan sebagai sumber energi yang murah dan tidak akan pernah habis, Karena kedua energi tersebut sifatnya tidak selalu ada, oleh Karena itu pembuatan pembangkit hibrida diharapkan dapat menutup kekurangan dari salah salu energi tersebut untuk dapat mengoptimalkan pengisian pada baterai akumulator.

Dari hasil pengujian alat secara keseluruhan diperoleh daya dari kedua pembangkit tersebut sebesar 17.2 Ah dalam kurun waktu 10 jam.

Kata Kunci : energi listrik, energi alternatif, pembangkit hibrida.

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DAFTAR ISI

LEMBAR PERSETUJUAN ....

ABSTRAK ii

KATA PENGANTAR iii

DAFTAR ISI v

DAFTAR GAMBAR viii

DAFTAR TABEL x

BAB I 1

PENDAHULUAN 1

1.1 Latar Belakang 1

1.2 Rumusan Masalah 3

1.3 Tujuan 3

1.4 Batasan Masalah 3

1.5 Metodologi Masalah 3

1.6 Sistematika Penulisan 4

BAB II 6

KAJIAN PUSTAKA 6

2.1 Pengertian Pembangkit Tenaga Hibrida 6

2.2 PLTBayu(angin) 6

2.2.1 Turbin Angin Sumbu Vertikal 6

2.2.2 Generator Sinkron Magnet Permanen 8

2.2.3 Stator 9

2.2.4 Rotor 9

2.2.5 Prinsip Kerja Generator 10

2.3 Panel Sel Surya 12

2.4 Kontroler 12

2.4.1 Dioda 13

2.4.2 DC Booster 13

2.4.3 Buck Konverter 13

2.5 Baterai Akumulator 14

BAB III 15

PERANCANGAN DAN PEMBUATAN ALAT 15

3.1 Pendahuluan 15

3.2 Perancangan Sistem ... 15
3.2.1 Prinsip Kerja ... 17
3.3 Perancangan Mekanik ... 18
3.4 Perancangan Pembangkit Listrik Tenaga Angin ... 19
3.4.1 Perancangan Kincir Angin Vertikal Savonius ... 19
3.4.2 Perancangan Generator Aksial Magnet Permanen ... 20
3.5 Perancangan Panel Sel Surya ... 24
3.6 Perancangan Kontroler ... 24
3.6.1 Perancangan Rangkaian Jembatan diode Penyearah ... 25
3.6.2 Perancangan DC Booster ... 25
3.6.3 Perencanaan Buck converter ... 26
3.7 Perancangan Baterai ... 26
3.8 Perancangan Keseluruhan Sistem ... 26
3.8.1 Fowchart Sistem ... 27
BAB IV ... 28
PENGUJIAN DAN PEMBAHASAN SISTEM ... 28
4.1 Pendahuluan ... 28
4.2 Pengujian Generator ... 28
4.2.1 Prosedur Pengujian ... 28
4.2.2 Pengujian Generator Tanpa Beban Tegangan AC 3 Fasa ... 29
4.2.3 Pengujian Gelombang Generator Menggunakan Osiloskop ... 30
4.2.4 Pengujian Generator Tanpa Beban Menggunakan Diode Penyearah ... 31
4.2.5 Pengujian Generator Dengan Beban Baterai Menggunakan DC Booster ... 32
4.2.6 Pengujian Generator Dengan Beban Lampu LED 12V 9W Menggunakan DC Booster ... 34
4.2.7 Hasil Pengujian Generator Untuk Pengisian Baterai Akumulator ... 35
4.3 Pengujian Panel Sel Surya ... 35
4.3.1 Prosedur Pengujian ... 35
4.3.2 Pengujian Panel Sel Surya Tanpa Beban ... 36
4.3.3 Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator 12V 100Ah Menggunakan Buck Converter ... 38
4.3.4 Hasil Pengujian Panel Sel Surya Untuk Pengisian Baterai Akumulator 12V 100Ah Menggunakan Buck Converter ... 39
4.4 Hasil Pengujian Kedua Pembangkit Dengan Beban Baterai Akumulator 12V/100Ah Menggunakan Buck boost converter ... 39

BAB V 41
PENUTUP 41
5.1 Kesimpulan 41
5.2 Saran 42
DAFTAR PUSTAKA .... **Error! Bookmark not defined.**

DAFTAR GAMBAR

Gambar 2. 1 Turbin Angin Sumbu Vertical Savonius 7
Gambar 2. 2 Generator Aksial Magnet Permanen 9
Gambar 2. 3 Stator Tanpa Inti Besi Pada Generator 9
Gambar 2. 4 Rotor Magnet Permanen pada Generator 10
Gambar 2. 5 Panel Sel Surya 12
Gambar 2. 6 Dioda Penyearah 13
Gambar 2. 7 DC Booster 13
Gambar 2. 8 Buck Converter 14
Gambar 2. 9 Baterai Akumulator 14
Gambar 3. 1 Flowchart Sistem Pembuatan 15
Gambar 3. 2 Blok Diagram Sistem 16
Gambar 3. 3 Perancangan Sistem Mekanik 18
Gambar 3. 4 Perancangan Kincir Angin Vertikal Savonius 19
Gambar 3. 5 Perancangan Kincir Angin Vertikal Savonius 20
Gambar 3. 6 Desain Generator Aksial Magnet Permanen 20
Gambar 3. 7 Magnet NdFeB 22
Gambar 3. 8 Perancangan Rotor 23
Gambar 3. 9 Perancangan Panel Sel Surya 24
Gambar 3. 10 Rangkaian Dioda Penyearah 3 Fasa 25
Gambar 3. 11 Perancangan DC Booster 25
Gambar 3. 12 Perancangan Buck Converter 26
Gambar 3. 13 Flowchart Keseluruhan Sistem 27
Gambar 4. 1 Blok Diagram Dengujian Generator Untuk Pengisian Baterai 29
Gambar 4. 2 Grafik Pengujian Keluaran Tegangan Generator AC 3Fasa 30
Gambar 4. 3 Gelombang Antar Fasa V-AB 30
Gambar 4. 4 Gelombang Antar Fasa V-AC 30
Gambar 4. 5 Gelombang Antar Fasa V-BC 31
Gambar 4. 6 Grafik Pengujian Tegangan DC Tanpa Beban 32
Gambar 4. 7 Grafik Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC Booster 33
Gambar 4. 8 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC Booster 33
Gambar 4. 9 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC Booster 33
Gambar 4. 10 Pengujian Generator Dengan Beban Lampu Led 12V 9W Menggunakan DC Booster 34
Gambar 4. 11 Blok Diagram Pengujian Panel Sel Surya Untuk Pengisian 36
Gambar 4. 12 Grafik Pengujian Panel Sel Surya Tanpa Beban 37
Gambar 4. 13 Gambar Pengujian Panel Sel Surya Tanpa Beban 37

Gambar 4. 14 Grafik Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator Menggunakan Buck Converter 38
Gambar 4. 15 Gambar Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator 39

DAFTAR TABEL

Tabel 2. 1 Tabel Kondisi Angin Yang Ideal Sebagai Pembangkit 7
Tabel 2. 2 Tabel Kondisi Angin Yang Ideal Sebagai Pembangkit Listrik............. 8
Tabel 3. 1 Spesifikasi Generator Aksial Magnet Permanen 21
Tabel 4. 1 Pengujian Generator AC/3Fasa... 29
Tabel 4. 2 Pengujian Tegangan DC Tanpa Beban 31
Tabel 4. 3 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC Booster... 32
Tabel 4. 4 Pengujian Generator Dengan Beban Lampu Led 12V 9W Menggunakan DC Booster... 34
Tabel 4. 5 Pengujian Panel Sel Surya Tanpa Beban 36
Tabel 4. 6 Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator Menggunakan Buck Converter 38
Tabel 4. 7 Pengujian Kedua Pembangkit Dengan Beban Baterai Akumulator Menggunakan Buck Boost Converter 39

BAB I
PENDAHULUAN

1.1 Latar Belakang

Dalam kondisi krisis energi sekarang ini negara-negara di dunia berlomba untuk mencari dan memanfaatkan sumber energi alternatif untuk menjaga keamanan ketersediaan sumber energinya. Krisis energi ini dikarenakan beberapa sebab diantaranya semakin berkurangnya sumber daya alam terutama minyak bumi, batu bara, dan gas alam. semakin bertambahnya jumlah sarana industri yang membutuhkan pasokan energi dari sumber daya alam. Dengan semakin berkembangnya teknologi di dunia, kebutuhan energi di dunia juga ikut meningkat. Kenaikan kebutuhan energi tersebut akan terus meningkat seiring kenaikan angka pertumbuhan penduduk di dunia. Sebagian besar energi yang dikonsumsi merupakan energi fosil yang tidak dapat diperbaharui (*irenewable resources*). Ketersediaan energi fosil sebagai sumber energi utama sangat terbatas dan terus mengalami ancaman kelangkaan kerena penggunaan energi tersebut dalam skala besar dan secara terus menerus. Perlu adanya sumber energi alternatif baru yang dapat diperbaharui (*renewable resources*) untuk menggantikan sumber energi fosil. Selain itu angka polusi yang diakibatkan dari pembangkitan energi bahan bakar fosil tersebut sangat besar.

Energi terbarukan berkembang pesat di dunia, seperti energi angin dan matahari, Sumber energi angin dan matahari merupakan sumber energi terbarukan yang bersih dan tersedia secara bebas. Masalah utama dari kedua jenis energi tersebut adalah tidak tersedia terus menerus. Energi angin hanya tersedia pada waktu yang seringkali tidak dapat diprediksi (*sporadic*), turbin angin pun banyak jenisnya, turbin horizontal dan turbin vertikal, kedua jenis turbin memiliki kelebihan dan kekurangan, turbin angin horizonal menggunakan blade atau baling baling untuk menerima gaya mekanis dari angin, serta harus menggunakan tower yang tinggi karena turbin angin horizontal memerlukan kecepatan angin yang besar dan arah turbin pun harus searah dengan angin, lalu turbin angin vertical juga memiliki tipe, dareus dan savonius, kedua jenis tipe tersebut mampu memanfaatkan angin dari berbagai macam arah, namun jenis dareus perlu menggunakan tower yg tinggi karena jenis dareus memerlukan kecepatan angin yang besar, sedangkan jenis savonius dapat di letakkan dekat dengan tanah dan dapat memanfaatkan angin dengan kecepatan kecil, untuk pembuatan turbin tersebut lebih memilih menggunakan turbin angin vertical jenis savonius karena dapat memanfaatkan energi angin walaupun kecepatan angin rendah, serta pembuatannya tidak memerlukan tower yang tinggi dan dapat diletakkan dekat dengan tanah, lalu pada pembangkit energi matahari, energi matahari tersedia pada waktu siang dan terang, tergantung terhadap cuaca. Untuk mengatasi permasalahan di atas teknik pembangkitan listrik tenaga hibrida angin dan matahari ini berfungsi sebagai penutup pada masing masing pembangkit untuk memaksimalkan pengisian pada baterai.

1.2 Rumusan Masalah

Berdasarkan latar belakang yang telah diutarakan di atas, maka dapat disimpulkan permasalahan yang diutarakan dalam penulisan skripsi ini, yaitu :

1. Bagaimana merancang sebuah pembangkit listrik tenaga hibrida angin dan surya agar dapat bekerja secara maksimal dan menghasilkan energi listrik yang optimal ?
2. Bagaimana cara menggabungkan kedua pembangkit antara pembangkit listrik tenaga angin dan surya ?

1.3 Tujuan

Perancangan dan pembuatan pembangkit listrik tenaga hibrida angin dan surya bertujuan untuk menciptakan pembangkit terbarukan yang bersih dan ramah lingkungan serta dapat menutupi kekuranganan pada masing-masing pembangkit.

1.4 Batasan Masalah

Agar tidak terjadi penyimpangan, maksud dan tujuan utama dari penyusunan skripsi ini maka perlu diberikan batasan masalah, antara lain:

1. Menggunakan generator AC 3 Fasa stator menggunakan 9 kutub dan menggunakan rotor 12 magnet.
2. Panel sel surya berkapasitas 100WP.
3. Tidak membahas masalah kontroler hibrida dan proteksi.
4. Tidak membahas masalah gaya mekanis angin dan kincir angin.
5. Pengujian di fokuskan pada pengisian pada baterei akumulator.
6. Alat ini di desain berkapasitas 100watt.

1.5 Metodologi Masalah

Metode yang digunakan dalam penyusunan skripsi ini adalah:

1. Studi literatur

   Mencari referensi, jurnal dan ide pengembangan yang berhubungan dengan perencanaan dan pembuatan alat yang akan dibuat.
2. Perancangan alat

Sebelum melaksanakan pembuatan dilakukan pendesainan dan perancangan alat tersebut.

3. Pengaplikasian alat

   Pada tahap pengaplikasian alat, dilakukan pembebanan untuk penerangan.

4. Pengujian alat

   Untuk mengetahui tingkat keberhasilan dari fungsi yang di buat dilakukan pengujian secara keseluruhan.

5. Analisa dan penarikan kesimpulan

   Melakukan analisa dari data yang di peroleh dari hasil pembangkitan listrik tenaga hibrida angin dan panel sel surya melalui pengujian alat sehingga dapat dibuat kesimpulan dari penelitian yg dilakukan.

1.6 Sistematika Penulisan

Untuk mendapatkan arah yang tepat mengenai hal - hal yang akan dibahas maka dalam skripsi ini disusun sebagai berikut :

BAB I : PENDAHULUAN

Memuat tentang latar belakang, rumusan masalah, tujuan, batasan masalah, metodelogi, dan sistematika penulisan.

BAB II : KAJIAN PUSTAKA

Pada bab ini di jelaskan mengenai dasar – dasar teori dalam penelitian secara singkat meliputi pembangkit listrik tenaga hybrid angin dan surya,

BAB III : PERANCANGAN DAN PEMBUATAN ALAT

Membahas tentang perencanaan dan proses pembuatan meliputi perencanaan, pembuatan alat, cara kerja dan penggunaan alat.

BAB IV : PENGUJIAN DAN ANALISA

Menjelaskan hasil analisa dari proses pengujian pada alat yang telah dibuat.

BAB V : PENUTUP

Berisi tentang semua kesimpulan yang berhubungan dengan penulisan skripsi, dan saran yang digunakan sebagai pertimbangan dalam pengembangan program selanjutnya.

DAFTAR PUSTAKA

BAB II
KAJIAN PUSTAKA

2.1 Pengertian Pembangkit Tenaga Hibrida

Pengertian Hibrida pada umumnya adalah penggunaan dua atau lebih pembangkit listrik dengan sumber energi yang berbeda.

Tujuan utama dari sistem hibrida pada dasarnya adalah berusaha menggabungkan dua atau lebih sumber energi (sistem pembangkit) sehingga dapat saling menutupi kelemahan masing-masing energi dan dapat mencapai target kebutuhan beban dan efisien pada beban tertentu.

Sistem Hibrida atau Pembangkit Listrik Tenaga Hibrida (PLTH) merupakan salah satu alternatif sistem pembangkit yang tepat diaplikasikan pada daerah-daerah yang sukar dijangkau oleh sistem pembangkit besar seperti jaringan PLN atau PLTD. PLTH ini memanfaatkan renewable energy sebagai sumber utama yang dikombinasikan dengan sumber energi cadangan.

Pada PLTH, renewable energy yang digunakan dapat berasal dari energi matahari, angin, dan lain-lain yang dikombinasikan dengan Generator Set sehingga menjadi suatu pembangkit yang lebih efisien, efektif dan handal untuk dapat mensuplai kebutuhan energi listrik baik sebagai penerangan rumah atau kebutuhan peralatan listrik yang lain.

2.2 PLTBayu(angin)

PLTBayu atau angin merupakan pembangkit listrik tenaga angin skala kecil, yang mungkin pernah kita jumpai pada daerah terpencil di daerah dekat pantai.

PLTBayu memiliki 3 komponen utama yaitu :

1. Angin, merupakan komponen utama untuk menggerakkan turbin angin.
2. Turbin angin, merupakan komponen untuk berinteraksi langsung dengan angin dan diubahnya menjadi daya mekanikal
3. Generator, merupakan alat yang mengubah energi mekanik menjadi energi listrik.

2.2.1 Turbin Angin Sumbu Vertikal

Turbin angin sumbu vertikal/tegak (atau TASV) memiliki poros/sumbu rotor utama yang disusun tegak lurus. Kelebihan utama dari turbin ini adalah turbin tidak harus diarahkan ke angin agar menjadi efektif. Kelebihan ini sangat berguna di tempat-tempat yang arah anginnya sangat bervariasi. TASV mampu memanfaatkan angin dari berbagai arah. Prinsip kerja TASV sangat sederhana, energi angin menggerakkan turbin angin dan menggerakkan poros turbin nantinya akan dirubah arah gerakannya oleh gearbox lalu diteruskan oleh rantai ke poros generator untuk dirubah menjadi energi listrik.

Gambar 2. 1 Turbin Angin Sumbu Vertical Savonius[3]

Tabel 2. 1 Tabel Kondisi Angin Yang Ideal Sebagai Pembangkit[5]

Tabel Kondisi Angin			
kelas angin	kecepatan angin m/d	kecepatan angin km/jam	kecepatan angin knot/jam
1	0.3 ~ 1.5	1 ~ 5.4	0.58 ~ 2.92
2	1.6 ~ 3.3	5.5 ~ 11.9	3.11 ~ 6.42
3	3.4 ~ 5.4	12.0 ~ 19.5	6.61 ~ 10.5
4	5.5 ~ 7.9	19.6 ~ 28.5	10.7 ~ 15.4
5	8.0 ~ 10.7	28.6 ~ 38.5	15.6 ~ 20.8
6	10.8 ~ 13.8	38.6 ~ 49.7	21 ~ 26.8
7	13.9 ~ 17.1	49.8 ~ 61.5	27.0 ~ 33.3
8	17.2 ~ 20.7	61.5 ~ 74.5	33.5 ~ 40.3
9	20.8 ~ 24.4	74.6 ~ 87.9	40.5 ~ 47.5

10	24.5 ~ 28.4	88.0 ~ 102.3	47.7 ~ 55.3
11	28.5 ~ 32.6	102.4 ~ 117.0	55.4 ~ 63.4
12	>32.6	>118	63.4

Tabel 2. 2 Tabel Kondisi Angin Yang Ideal Sebagai Pembangkit Listrik[5]

Tingkat Kecepatan Angin 10 Meter di Atas Permukaan Tanah		
Kelas Angin	Kecepatan Angin m/d	Kondisi Alam di Dataran
1	0.00 ~ 0.02	--------------------------------------
2	0.3 ~ 1.5	angin tenang, asap lurus ke atas
3	1.5 ~ 3.3	asap bergerak mengikuti arah angin
4	3.4 ~ 5.4	wajah terasa ada angin, daun2 bergoyang pelan, petunjuk arah angin bergerak
5	5.5 ~ 7.9	debu jalan, kertas beterbangan, ranting pohon bergoyang
6	8.0 ~ 10.7	ranting pohon bergoyang, bendera berkibar
7	10.8 ~ 13.8	ranting pohon besar bergoyang, air berombak kecil
8	13.9 ~ 17.1	ujung pohon melengkung, hembusan angin terasa di telinga
9	17.2 ~ 20.7	dapat mematahkan ranting pohon, jalan berat melawan arah angin
10	20.8 ~ 24.4	dapat mematahkan ranting pohon, rumah rubuh
11	24.5 ~ 28.4	dapat menumbangkan pohon, menimbulkan kerusakan
12	28.5 ~ 32.6	menimbulkan kerusakan parah
13	32.7 ~ 35.9	Tornado

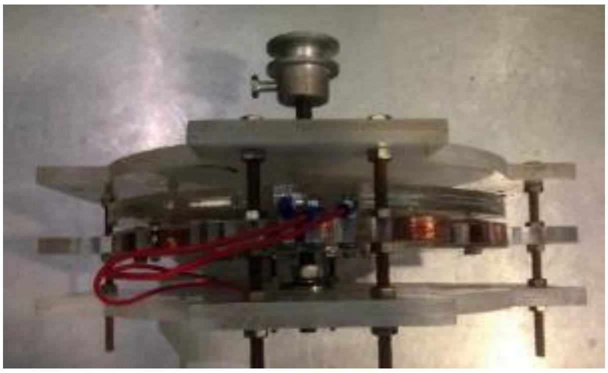
Angin kelas 3 adalah batas minimum dan angin kelas 8 adalah batas maksimum energi angin yang dapat dimanfaatkan untuk menghasilkan energi listrik.

2.2.2 Generator Sinkron Magnet Permanen

Secara garis besar, generator sinkron magnet permanen dibagi menjadi dua jenis bila dilihat dari fluks magnet yang dihasilkan, yaitu :

1. Generator magnet permanen dengan fluks radial/Generator MPFR (*Radial Flux Permanent Magnet Generator*)
2. Generator magnet permanen dengan fluks aksial/Generator MPFA (*Axial Flux Permanent Magnet Generator*)

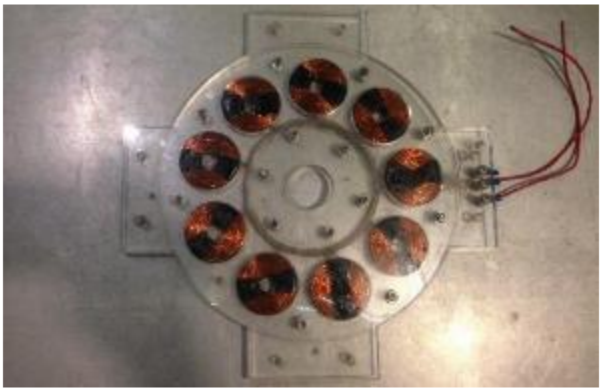
Pada skripsi ini, membahas mengenai generator sinkron magnet permanen, fluks aksial dengan rotor berbentuk piringan. Pada gambar 2.2 merupakan gambar generator sinkron magnet permanen fluks aksial.



Gambar 2. 2 Generator Aksial Magnet Permanen

2.2.3 Stator

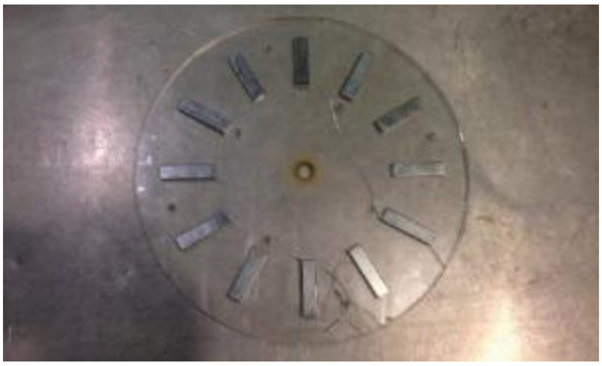
Stator adalah bagian yang diam dari generator yang berfungsi sebagai tempat kumparan jangkar. Bentuk stator pada perancangan ini adalah stator tanpa inti besi, pada gambar 2.3 merupakan bentuk stator tanpa inti besi.



Gambar 2. 3 Stator Tanpa Inti Besi Pada Generator

2.2.4 Rotor

Rotor adalah bagian yang berputar, rotor merupakan tempat meletakkan magnet permanen, dimana pada inti rotor tersebut telah dibentuk ruang untuk meletakkan magnet permanen. Rotor dari sebuah permanent magnet generator seperti pada gambar 2.4 berikut.



Gambar 2. 4 Rotor Magnet Permanen pada Generator

2.2.5 Prinsip Kerja Generator

Prinsip dasar generator arus bolak balik (AC) menggukan hukum faraday yang menyatakan jika sebatang penghantar berada pada medan magnet yang berubah ubah, maka pada penghantar tersebut akan terbentuk gaya gerak listrik

Hubungan antara kecepatan putar dan frekuensi generator dapat dirumuskan pada persamaan berikut ini:

2.2.5.1. Rasio Per Menit (RPM)

Kecepatan medan putar stator berbanding terbalik dengan jumlah kutub berdasarkan putaran permenit hal ini dapat dinyatakan dalam persamaan sebagai berikut :

$$n = \frac{120\,f}{p} \quad \text{(2.1)}$$

n = putaran (rpm)

f = frequensi (Hz)

p = jumlah kutub

2.2.5.2 Fluks Magnet

Nilai kerapatan fluks maksimum adalah :

$$Bmax = Br\,.\frac{lm}{lm+\delta} \quad \text{(2.2)}$$

Dimana :

Br : Residual induction (T)

Lm : tinggi magnet (m)

δ : lebar celah udara

$Bmax$: fluks maksimal (T)

2.2.5.3 Luasan Magnet

Perancangan letak magnet pada rotor generator sebagai berikut :

$$A_{magn} = \frac{\pi(\,ro^2 - ri^2) - \tau f(ro - ri)Nm}{Nm} \qquad (2.3)$$

Dimana :

A_{magn} : Luasan Magnet (m^2)

ro : Radius luar magnet (m)

ri : Radius dalam magnet (m)

τf : jarak antar magnet (m)

Nm : jumlah magnet

2.2.5.4 Fluks Maksimal Yang Di Hasilkan

$$\emptyset_{max} = A_{magn} \, . \, B_{max} \qquad (2.4)$$

Dimana :

$\emptyset_{max}$: Fluks maksimum

A_{magn} : luasan magnet

B_{max} : kerapatan fluks

2.2.5.5 Tegangan Induksi

Tegangan induksi dapat dihitung melalui persamaan berikut :

$$E_{rms} = 4.44 \, . N \, . f \, . \emptyset_{max} \, . Ns \qquad (2.5)$$

N : jumlah lilitan

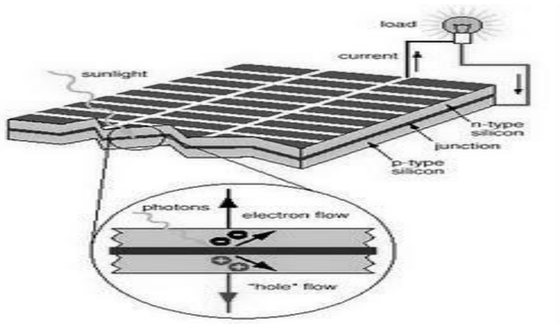
F : frekuensi (Hz)

$\emptyset_{max}$: fluks maksimal (Wb)

Ns : jumlah kumparan

2.3 Panel Sel Surya

Panel sel surya adalah alat yang terdiri dari sel surya yang merubah cahaya menjadi listrik. Mereka disebut surya atau matahari atau "*sol*" karena matahari merupakan sumber cahaya terkuat yang dapat dimanfaatkan. Panel surya sering kali disebut sel *photovoltaic*, *photovoltaic* dapat diartikan sebagai "cahaya listrik". Sel surya bergantung pada efek *photovoltaic* untuk menyerap energi. Pada umumnya, sel surya merupakan sebuah lempengan semi konduktor yang dapat menyerap photon dari sinar matahari dan mengubahnya menjadi listrik. Sel surya tersebut dari potongan silikon yang sangat kecil dengan dilapisi bahan kimia khusus untuk membentuk dasar dari sel surya. Sel surya pada umumnya memiliki ketebalan minimum 0,3 mm yang terbuat dari irisan bahan semikonduktor dengan kutub positif dan negatif. Pada sel surya terdapat sambungan antara dua lapisan tipis yang terbuat dari bahan semikonduktor yang masing - masing yang diketahui sebagai semikonduktor jenis “P” (positif) dan semikonduktor jenis “N” (Negatif). Silikon jenis P merupakan lapisan permukaan yang dibuat sangat tipis supaya cahaya matahari dapat menembus langsung mencapai *junction*. Bagian P ini diberi lapisan nikel yang berbentuk cincin, sebagai terminal keluaran positif . Dibawah bagian P terdapat bagian jenis N yang dilapisi dengan nikel juga sebagai terminal keluaran negatif.



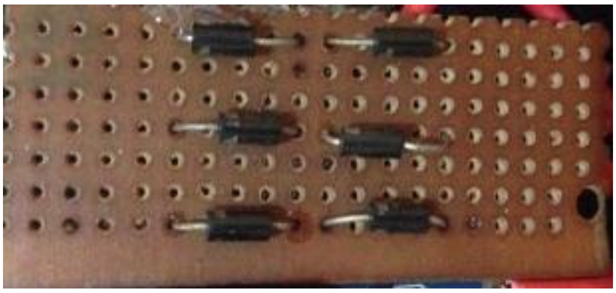
Gambar 2. 5 Panel Sel Surya

2.4 Kontroler

Kontroler disini berfungsi untuk mengatur keluaran dari masing masing pembangkit yang nantinya diperuntukan sebagai pengisian baterai akumulator.

2.4.1 Dioda

Dioda hanya dapat dialiri arus listrik secara satu arah saja. Prinsip inilah yang digunakan untuk merubah arus AC yang dibangkitkan di kumparan stator menjadi arus DC.



Gambar 2. 6 Dioda Penyearah

2.4.2 DC Booster

DC *Booster* merupakan suatu modul yang berfungsi untuk menaikkan tegangan DC dan mengatur tegangan *output*annya, pada aplikasinya DC *Booster* ini mengatur nilai tegangan pada saat pengisian baterai.

Gambar 2. 7 DC *Booster*

2.4.3 Buck Converter

Buck converter adalah suatu modul yang berfungsi untuk menurunkan tegangan DC dan mengatur tegangan outputnya, pada aplikasinya hampir sama dengan DC *Boster* untuk mengatur tegangan pada saat pengisian baterai.

Gambar 2. 8 *Buck Converter*

2.5 Baterai Akumulator

Beterai adalah alat listrik kimia yang menyimpan energi dan mengeluarkannya dalam bentuk listrik. Baterai terdiri dari tiga komponen, yaitu:

1. Batang karbon sebagai anoda
2. Seng (Zn) sebagai katoda
3. Pasta sebagai elektrolit atau penghantar

Gambar 2. 9 Baterai Akumulator

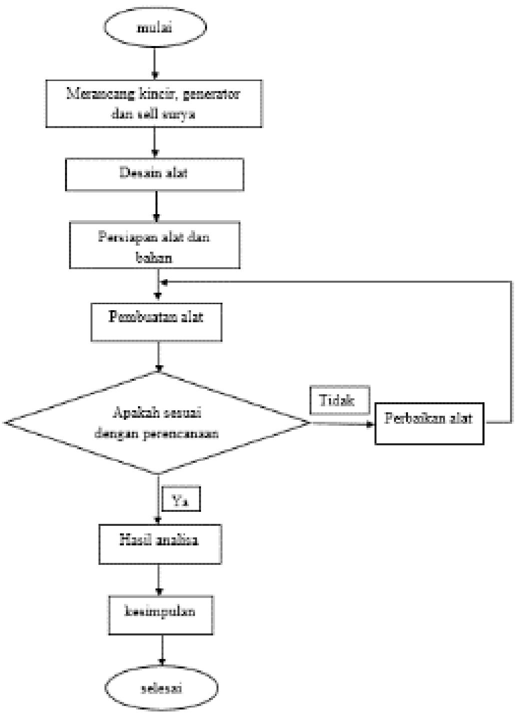
BAB III
PERANCANGAN DAN PEMBUATAN ALAT

3.1 Pendahuluan

Pada bab ini akan membahas tentang perencanaan dan proses pembuatan meliputi perencanaan, pembuatan alat, cara kerja dan penggunaan alat, sehingga tujuan dari perencanaan dapat tercapai dengan baik. Untuk itu pembahasan difokuskan pada desain yang telah direncanakan pada blok diagram sistem.

3.2 Perancangan Sistem

Sistem yang akan dirancang akan di lakukan secara bertahap. Berikut tahapan yang dilakukan untuk menyelesaikan skripsi ini adalah

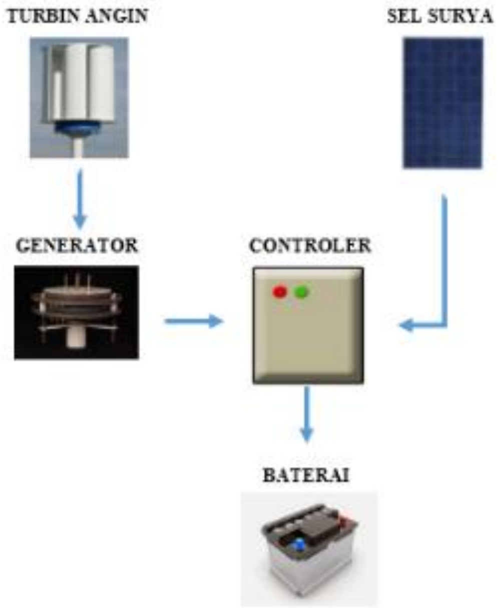


Gambar 3. 1 *Flowchart* Sistem Pembuatan

Tahapan awal dalam menyelesaikan skripsi ini dimulai dengan membangun ide awal dilanjutkan dengan studi literatur untuk mencari informasi dan data-data yang diperlukan, pencarian informasi mengenai dasar teori terutama tentang pembangkit hibrida, dan dasar teori mengenai turbin angin, konsep generator magnet permanen, panel sel surya dan cara pengisian ke baterai.

Pembuatan pembangkit terdiri dari beberapa tahapan, yaitu :

1. Pembuatan sudu turbin secara vertikal dan pembuatan transmisi dengan menggunakan *gear box*, kemudian
2. Pembuatan generator aksial meliputi pembuatan rotor dengan menggunakan magnet permanent, penggulungan lilitan stator serta pembuatan rumah bagi generator aksial.
3. Perakitan panel sel surya.
4. Pengontrolan agar pembangkit dapat mengisi baterai.



Gambar 3. 2 Blok Diagram Sistem

Penjelasan blok diagram sebagai berikut :

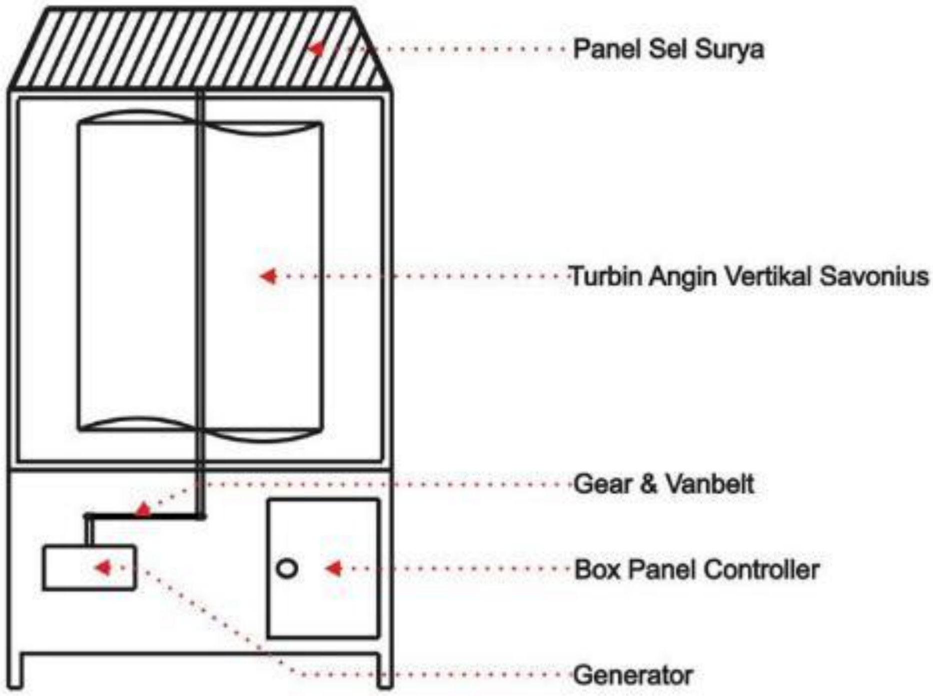
1. Kincir angin vertikal savonius berfungsi mengubah energi angin menjadi energi kinetik.
2. Generator berfungsi sebagai alat untuk megubah energi kinetik menjadi energi listrik.
3. Panel sel surya berfungsi untuk mengkonversi cahaya matahari menjadi energi listrik.

4. Kontroler disini berfungsi sebagai pengontrolan untuk pengisian baterai, meliputi penyetabilan tegangan dan step up tegangan, agar dapat memenuhi standar nominal tegangan dalam baterai.
5. Baterai berfunsi sebagai alat penyimpan energi listrik yang di keluarkan dari oleh generator dan panel sel surya.

3.2.1 Prinsip Kerja

Prinsip kerja dari pembangkit listrik hibrida menggunakan kincir angin sumbu vertikal savonius dan panel sel surya ini adalah untuk menutupi kekurangan dari masing-masing pembangkit yang dihasilkan dari sumber energi berbeda, dengan menggunakan pembangkin energi angin dan energi sinar matahari ini diharapkan dapat menghasilkan energi listrik yang maksimal. Turbin angin sumbu vertikal savonius dapat bekerja meskipun arah angin berubah-ubah dan mampu mendayagunakan angin dari berbagai arah, dari putaran turbin tersebut dimanfaatkan untuk menggerakkan generator, untuk mendapatkan putaran yang besar maka digunakan gear pembanding agar perbandingan putaran generator lebih besar dari putaran turbin angin, semakin besar putaran generator maka semakin besar pula tegangan yang dihasilkan, karena generator ini adalah generator AC (*alternative current*) maka outputan generator tersebut perlu disearahkan terlebih dahulu menggunakan diode yang telah di rangkai seri pararel membentuk jembatan diode, prinsip kerja diode tersebut hanya melewatkan arus satu arah saja. Setelah outputan dari generator tersebut menjadi tegangan DC (*direct current*) lalu tegangan tersebut di naikan dan di stabilkan dengan menggunakan DC *Booster* untuk pengisian pada baterai. Begitu juga dengan sel surya, prinsip kerja sel surya tersebut adalah mengkonversi atau mengubah energi dari cahaya matahari menjadi energi listrik, proses pengubahan atau konversi cahaya matahari menjadi listrik tersebut karena bahan yang disusun menjadi sel surya berupa bahan semikonduktor, lebih tepatnya tersusun atas dua jenis semikonduktor, yaitu jenis n dan jenis p, semikonduktor jenis n merupakan semikonduktor yang memiliki kelebihan elektron, sehingga kelebihan muatan negatif, (n = negatif). Sedangkan semikonduktor jenis p memiliki kelebihan hole, sehingga disebut dengan p (p = positif) karena kelebihan muatan positif, pada awalnya pembuatan dua jenis semikonduktor ini dimaksudkan untuk meningkatkan tingkat konduktifitas atau tingkat kemampuan daya hantar listrik dan panas semikonduktor, di dalam semikonduktor ini elektron maupun hole memiliki jumlah yang sama, kelebihan elektron atau hole dapat meningkatkan daya hantar listrik maupun panas dari sebuah semikoduktor. Lalu outputan dari sel surya tersebut di naikan dan di stabilkan dengan menggunakan voltage regulator untuk pengisian pada baterai. Baterai yang digumakan tersebut adalah baterai basah atau aki basah, prinsip kerja pada aki basah ini mengubah listrik tersebut menjadi kimia, dengan menggunakan bahan batang karbon sebagai anoda, bahan seng (Zn) sebagai katoda dan pasta sebagai elektrolit atau penghantar, ketika semua outputan telah melalui baterai sebagai alat penampung energi listrik maka outputan dari baterai tersebut dapat digunakan untuk pembebanan.

3.3 Perancangan Mekanik

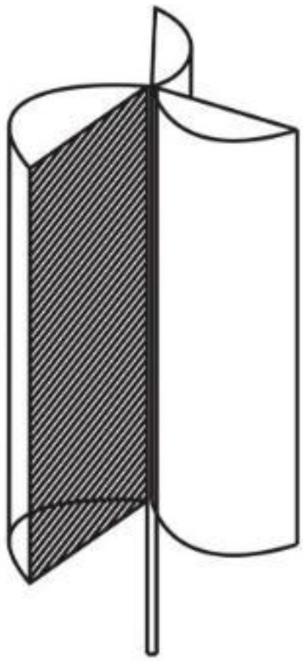


Gambar 3. 3 Perancangan Sistem Mekanik

3.4 Perancangan Pembangkit Listrik Tenaga Angin

3.4.1 Perancangan Kincir Angin Vertikal Savonius

Perancangan turbin angin vertikal savonius dimulai dari pendesainan sudu sudu turbin, pada perancangan ini menggunakan 3 buah sudu, bahan yang digunakan turbin menggunakan bahan dari plat besi dan seng, spesifikasi luas pada sudu sudu tersebut adalah tinggi 75cm dan lebar 25cm. Turbin angin vertical savonius ini berfungsi sebagai penggerak utam pada generator, pada Gambar ini adalah desain perancangan turbin angin vertical savonius.

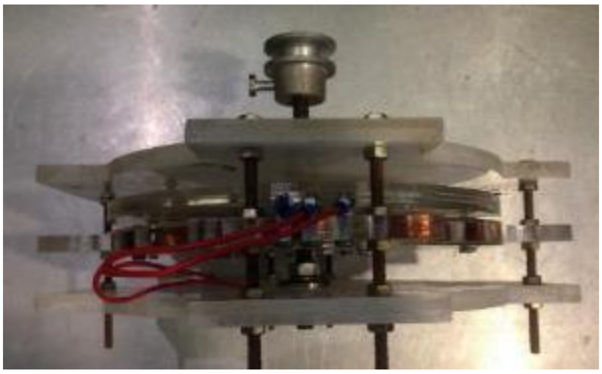


Gambar 3. 4 Perancangan Kincir Angin Vertikal Savonius

Gambar 3. 5 Perancangan Kincir Angin Vertikal Savonius

3.4.2 Perancangan Generator Aksial Magnet Permanen

Perancancangan generator ini menggunakan bahan akrilik sebagai rumah dari kumparan dan magnet, pada stator terdiri dari 9 kutup, masing-masing kutup berdiameter 5cm, 180 lilitan dengan penampang 0,75 mm , pada rotor menggunakan 12 kutub magnet, magnet yang digunakan adalah magnet permanen jenis neodymium berukuranan 40mmx10mmx2mm. yang dipasang hanya satu sisi dan dipasang behadap hadapan dengan stator.



Gambar 3. 6 Desain Generator Aksial Magnet Permanen

Tabel 3. 1 Spesifikasi Generator Aksial Magnet Permanen

Stator		**Rotor**	
Kutub	9	Kutub	12
Lilitan	180		
Besar penampang	0,75 mm	Luas magnet	10x40x2mm
Diameter kumparan	5cm		

3.4.2.1 Perencanaan Tegangan Keluaran

Generator ini di rancang untuk bekerja pada frekuensi 50 Hz dan berputar pada kecepatan 667 tegangan keluaran di rancang 2,9 Volt pada kondisi tanpa beban, kemudian disearahkan dan dinaikan menggunakan booster untuk pengisian baterei akumulator, tegangan induksi generator dapat dihitung dengan persamaan berikut :

3.4.2.2 Rasio Per Menit

Hubungan antar kecepatan putar dan frekuensi generator dapat di rumuskan pada persamaan berikut ini :

$$n = \frac{120\,f}{p}$$

Dimana :

n = putaran (Rpm)

f = frequensi (Hz)

p = jumlah kutup

$$n = \frac{120\,.\,50}{9}$$

= 666 Rpm

3.4.2.3 Perencanaan Magnet Permanen

Magnet permanen di gunakan untuk menghasilkan fluks magnet. Magnet permanen yang digunakan adalah, batang material rare-earth, bertype neodymium-iron-boron NdFeB.

Gambar 3. 7 Magnet NdFeB[5]

Magnet NdFeB yang digunakan berdimensi

P = 4cm

L = 1cm

T = 0,2cm

Nilai besaran fluks yang dihasilkan saat celah udara minimal (0,01 m) adalah :

$$Bmax = Br \,.\, \frac{lm}{lm + \delta}$$

Dimana :

Br : Residual induction (T)

Lm : tinggi magnet (m)

δ : lebar celah udara

$Bmax$: fluks maksimal (T)

$$Bmax = 1.15 \,.\, \frac{0.004}{0.004 + 0.01}$$

= 0,328

3.4.2.4 Perancangan Rotor

Perancangan rotor berfungsi sebagai kumparan medan, dan untuk menghasilkan medan magnet dibutuhkan magnet permanen magnet permanen yang digunakan adalah magnet batang berjenis (NdFeB) jumlah magnet yang digunakan 12 buah untuk tiap rotor.

Gambar 3. 8 Perancangan Rotor

$$A_{magn} = \frac{\pi(\,ro^2 - \,ri^2) - \tau f(ro - ri)Nm}{Nm}$$

Dimana :

ro : 10.7 cm

ri : 6.7 cm

τf : 0.9 cm

Nm : 12

$$= \frac{3.14(\,0.107^2 - \,0.067^2) - 0.025(0.107 - 0.067)12}{12}$$

= 0.2502 x 10^{-4} m^2

3.4.2.5 Fluks Maksimum Yang Di Hasilkan

$\emptyset_{max} = \; A_{magn} \, . \; B_{max}$

= 0,2502 x 10^{-4} . 0,328

= 0,0820656 x 10^{-4} wb

$\emptyset_{max}$: Fluks maksimum

A_{magn} : luasan magnet

B_{max} : kerapatan fluks

3.4.2.6 Tegangan Induksi

Tegangan E_{rms} yang di bangkitkan generator adalah

$E_{rms} = 4.44 \, . N \, . f \, . \emptyset_{max} \, . Ns$

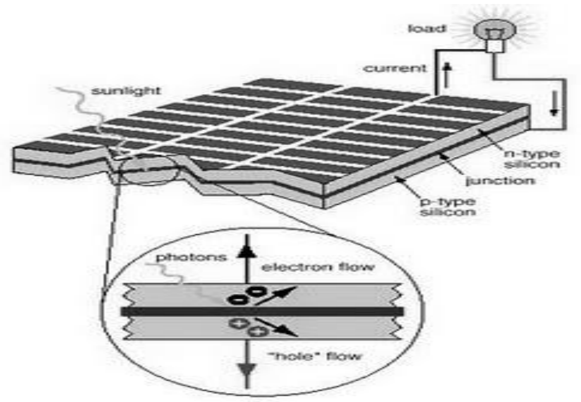
$E_{rms} = 4.44 \, . \, 180 \, . \, 50 \, .$ 0,0820656 x 10^{-4} wb . 9

= 2,951 Volt

N	: jumlah lilitan
F	: frequensi (Hz)
$\emptyset_{max}$	: fluks maksimal (Wb)
Ns	: jumlah kumparan

3.5 Perancangan Panel Sel Surya

Sel surya merupakan alat yang dapat mengubah cahaya matahari menjadi energi listrik, Karena komponen yang dipergunakan berbahan semi konduktor, cahaya yang diserap membuat elektron menjauh dan membuat elektron bergerak bebas, PV cells juga mempunyai satu atau lebih medan listrik yang memaksa elektron untuk bergerak dengan arah tertentu, aliran elektron ini merupakan arus listrik. Energi listrik yang dihasilkan dari satu sel surya sangat kecil, maka beberapa sel surya harus digabungkan sehingga terbentuklah satuan komponen yang disebut *module.* Pada perancangan panel sel surya, menggunakan panel sel surya pabrikasi, dengan spesifikasi panel sel surya 100 Wp, yang diharapkan mampu mengeluarkan tegangan di atas 14.5 Volt



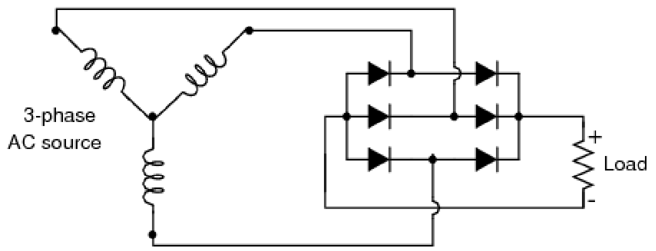
Gambar 3. 9 Perancangan Panel Sel Surya[5]

3.6 Perancangan Kontroler

Perancangan kontroler bertujuan untuk mengatur tegangan dan arus yang akan di pergunakan untuk pengisian baterai, meliputi komponen penyearah dan pengaturan tegangan.

3.6.1 Perancangan Rangkaian Jembatan Diode Penyearah

Rangkaian jembatan diode berfungsi sebagai penyearah arus untuk outputan dari generator agar menjadi arus searah atau DC, dengan rangkaian ini outputan dari diode menjadi searah atau DC.

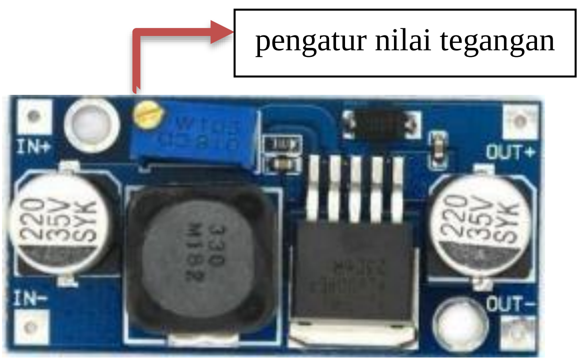


Gambar 3. 10 Rangkaian Dioda Penyearah 3 Fasa

(Sumber : http://trikueni-desain-sistem.blogspot.co.id/2013/10/Rangkaian-Dioda-Penyearah.html)

3.6.2 Perancangan DC Booster

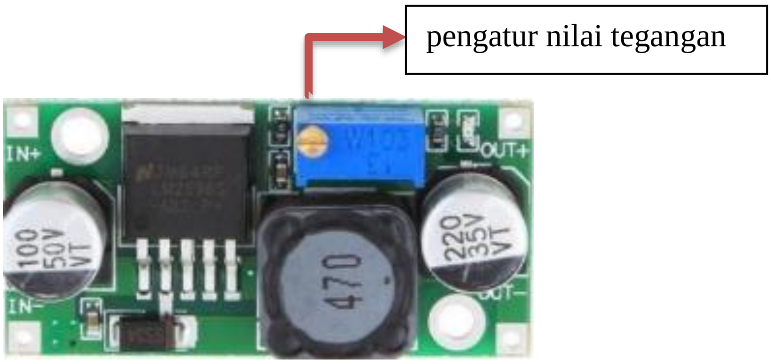
Dalam perancangan penaik dan penyetabil tegangan ini menggunakan modul *Booster* pabrikasi yang berfungsi mengatur nilai tegangan untuk pengisian pada baterai, baterai yang digunakan adalah baterai 12 Volt, maka baterai tersebut hanya mau di isi dengan tegangan di atas 12 Volt, maka regulator tersebut mengatur nilai tegangan agar di atas 12 panel sel surya Volt, dengan tegangan pengisian nominal 14.5 Volt.



Gambar 3. 11 Perancangan DC *Booster*

3.6.3 Perencanaan Buck Converter

Dalam perancangan penurun dan penyetabil tegangan ini menggunakan *Buck Converter* pabrikasi yang berfungsi menurunkan tegangan dan mengatur nilai tegangan untuk pengisian pada baterai, dengan tegangan pengisian nominal 14.5 Volt.



Gambar 3. 12 Perancangan *Buck Converter*

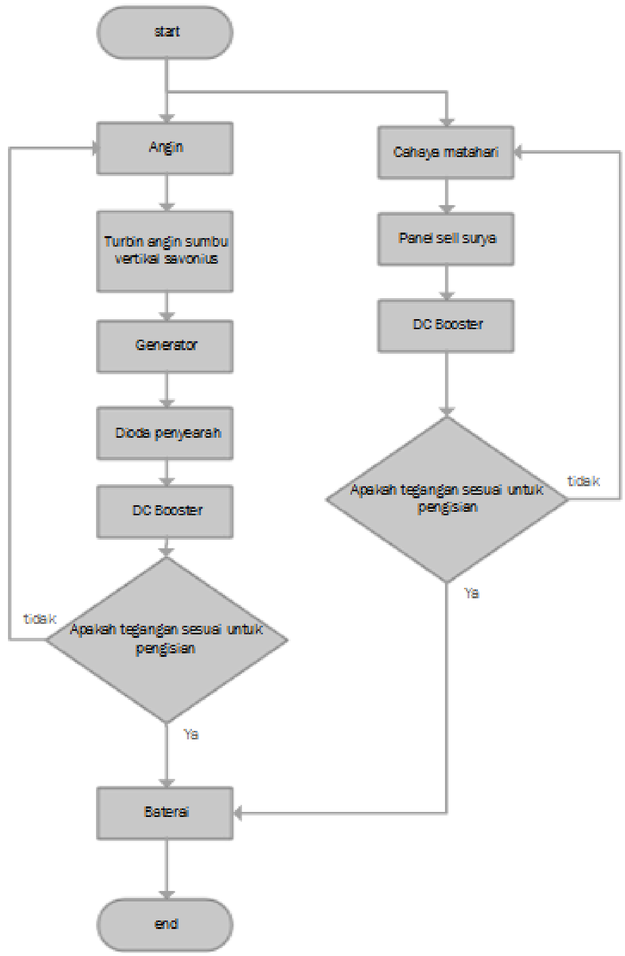
3.7 Perancangan Baterai

Baterai merupakan alat untuk menyimpan arus dan tegangan, penyimpanan tersebut berbentuk kimia lalu dikeluarakan dalam bentuk energi listrik. Baterai yg digunakan adalah baterai basah atau aki basah dengan tegangan 12 Volt dan berkapasitas 100 Ah.

3.8 Perancangan Keseluruhan Sistem

Bagaimana perancangan keseluruhan system ini dapat berjalan sesuai perencanan yang telah di buat, agar memperoleh hasil yang sesuai dengan apa yang telah di rancang, perancangan keseluruhan ini dilakukan dengan perencanaan pembuatan *flowchart*.

3.8.1 Flowchart Sistem



Gambar 3. 13 *Flowchart* Keseluruhan Sistem

BAB IV
PENGUJIAN DAN PEMBAHASAN SISTEM

4.1 Pendahuluan

Pada bab ini membahas tentang pengujian serta pembahasan hasil perancangan dari sistem yang telah dirancang sebelumnya agar dapat diketahui bagaimana kinerja dari keseluruhan sistem maupun kinerja masing – masing bagian. Secara umum pengujian ini untuk megetahui apakah piranti yang direalisasikan dapat bekerja sesuai dengan perencanaan.

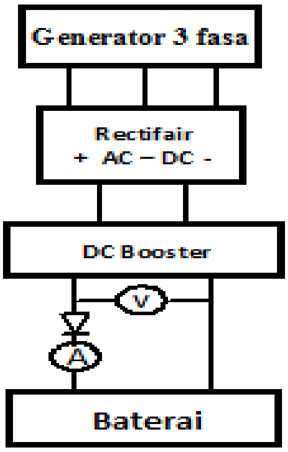
4.2 Pengujian Generator

Pengujian ini bertujuan untuk melihat hasil seberapa besar keluaran generator yg dihasilkan dengan kecepatan berfariasi dengan mengkopel generator dengan motor.

4.2.1 Prosedur Pengujian

Pengujian ini dilakukan dengan tanpa melakukan beban lampu tetapi langsung ke baterai, hal ini dilakukan untuk mengetahui seberapa besar daya dan arus yang dihasil oleh generator dengan kecepatan tertentu.

1. Merangkai dan menghubungkan generator dengan alat ukur multimeter.
2. Mengukur kecepatan generator untuk mengetahui tegangan antar fasa dari keluaran generator 3 fasa.
3. Mengukur gelombang antar fasa menggunakan alat osiloskop
4. Mengukur kecepatan generator untuk mengetahui tegangan keluaran setelah di pasang diode penyearah.
5. Mengukur kecepatan generator untuk mengetahui tegangan dan arus keluaran setelah di pasang DC *Booster* dan di bebani baterei sesuai gambar 4.1 di bawah ini.



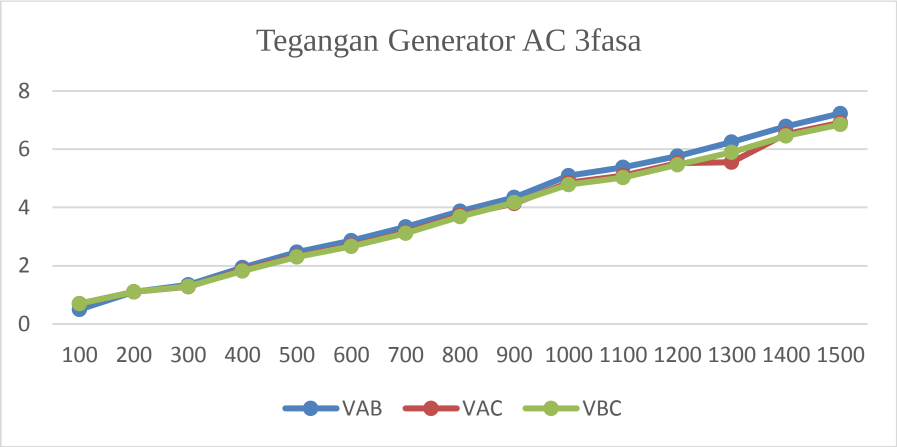
Gambar 4. 1 Blok Diagram Dengujian Generator Untuk Pengisian Baterai

4.2.2 Pengujian Generator Tanpa Beban Tegangan AC 3 Fasa

Hasil pengujian generator tanpa beban tegangan AC 3 Fasa

RPM	V		
	AB	AC	BC
100	0,5	0,7	0,7
200	1,1	1,1	1,1
300	1,35	1,28	1,29
400	1,94	1,85	1,82
500	2,47	2,32	2,30
600	2,86	2,69	2,67
700	3,34	3,15	3,11
800	3,87	3,73	3,69
900	4,35	4,14	4,17
1000	5,09	4,85	4,79
1100	5,38	5,09	5,03
1200	5,76	5,52	5,47
1300	6,25	5,55	5,89
1400	6,78	6,52	6,46
1500	7,23	6,91	6,85

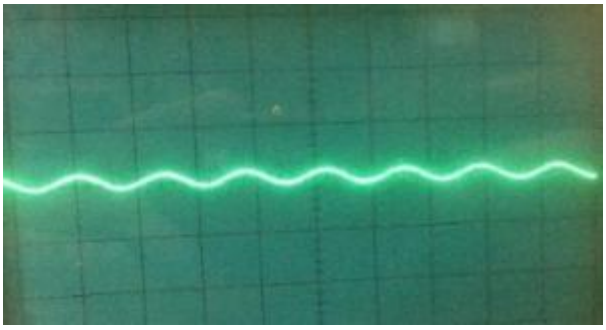
Tabel 4. 1 Pengujian Generator AC/3Fasa



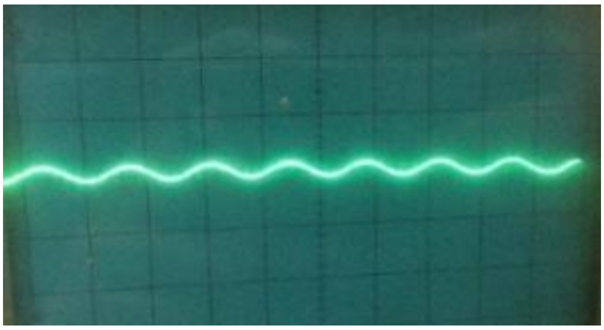
Gambar 4. 2 Grafik Pengujian Keluaran Tegangan Generator AC 3Fasa

Data yang diperoleh dari hasil pengukuran semakin besar kecepatan maka semakin besar tegangan yang dihasilkan. Dan ada selisih sedikit berbeda pada fasa VAC sedikit turun.

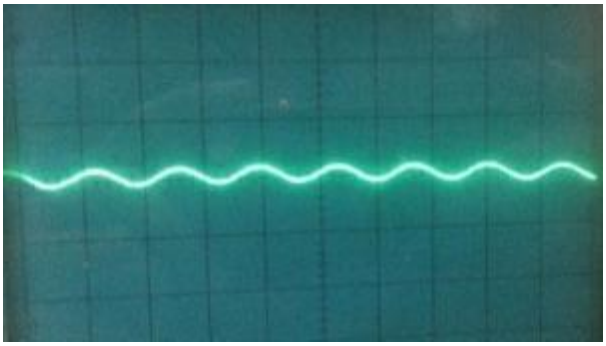
4.2.3 Pengujian Gelombang Generator Menggunakan Osiloskop



Gambar 4. 3 Gelombang Antar Fasa V-AB



Gambar 4. 4 Gelombang Antar Fasa V-AC



Gambar 4. 5 Gelombang Antar Fasa V-BC

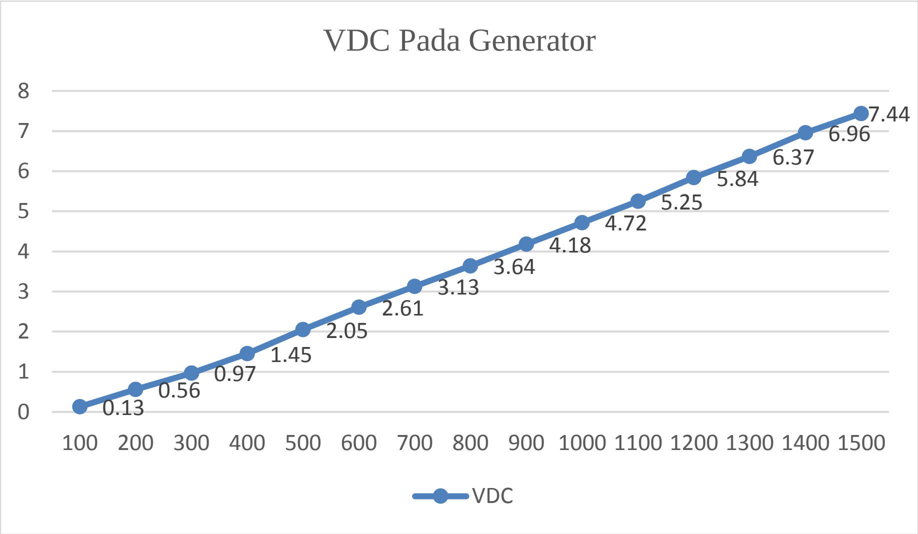
Pada pengujian gelombang menggunakan osiloskop rata rata gelombang antar fasa yg di bangkitkan hampir sama antara VAB VAC dan VBC.

4.2.4 Pengujian Generator Tanpa Beban Menggunakan Diode Penyearah

Hasil pengujian tegangan DC tanpa beban

Tabel 4. 2 Pengujian Tegangan DC Tanpa Beban

RPM	VDC
100	0.13
200	0.56
300	0.97
400	1.45
500	2.05
600	2.61
700	3.13
800	3.64
900	4.18
1000	4.72
1100	5.25
1200	5.84
1300	6.37
1400	6.96
1500	7.44



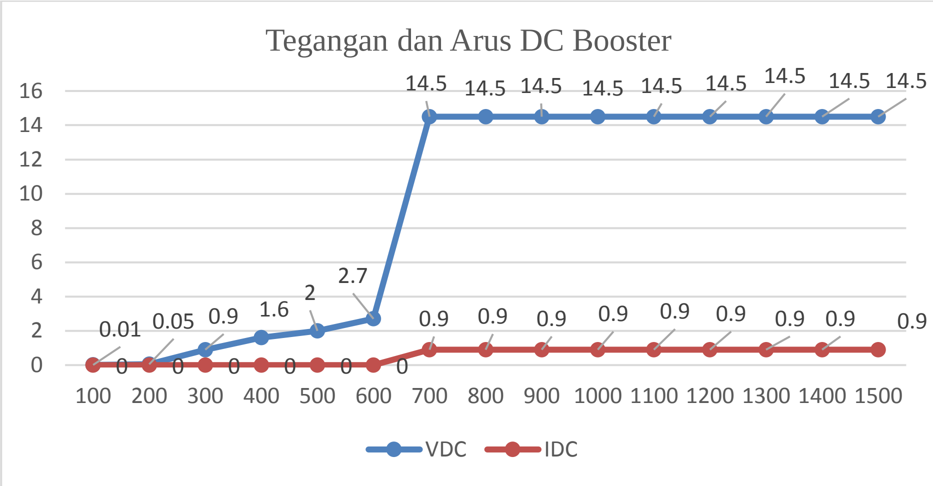
Gambar 4. 6 Grafik Pengujian Tegangan DC Tanpa Beban

Pada pengujian generator setelah melewati diode penyearah telah di peroleh data dengan RPM 1500 mengeluarkan tegangan DC sebesar 7.44 volt.

4.2.5 Pengujian Generator Dengan Beban Baterai Menggunakan DC Booster

Tabel 4. 3 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC *Booster*

RPM	VDC	IDC
100	0.01	0
200	0.05	0
300	0.9	0
400	1.6	0
500	2.0	0
600	2.7	0
700	14.5	0.9
800	14.5	0.9
900	14.5	0.9
1000	14.5	0.9
1100	14.5	0.9
1200	14.5	0.9
1300	14.5	0.9
1400	14.5	0.9
1500	14.5	0.9



Gambar 4. 7 Grafik Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC *Booster*

Gambar 4. 8 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC *Booster*

Gambar 4. 9 Pengujian Generator Tegangan DC Dengan Beban Baterai Menggunakan DC *Booster*

DC *Booster* dapat bekerja dan menaikkan tegangan dengan inputan minimal 3Volt, dalam pengukuran tersebut dengan rpm 700 dapat menghasilkan RPM 3Volt dan dapat mengisi baterai dengan daya 0.9 Ampere. Maka dengan rpm 700 tegangan dan daya yang dikeluarkan untuk pengisian baterai akumulator sudah stabil.

4.2.6 Pengujian Generator Dengan Beban Lampu LED 12V 9W Menggunakan DC Booster

Tabel 4. 4 Pengujian Generator Dengan Beban Lampu Led 12V 9W Menggunakan DC *Booster*

RPM	VDC	IDC	KETERANGAN
100	0.01	0	Mati
200	0.05	0	Mati
300	0.9	0	Mati
400	1.6	0	Mati
500	2.0	0	Mati
600	2.7	0	Mati
700	8.42	0.2	Redup
800	8.82	0.4	Redup
900	9.24	0.6	Redup
1000	9.57	0.8	Terang
1100	9.70	0.9	Terang
1200	9.88	1.0	Terang
1300	10.10	1.1	Terang
1400	10.31	1.3	Terang
1500	10.44	1.4	Terang

Gambar 4. 10 Pengujian Generator Dengan Beban Lampu Led 12V 9W Menggunakan DC *Booster*

Pada pengujian generator dengan beban lampu LED 12V 9W menggunakan DC Booster lampu pada Rpm 700 dapat menyala namun redup namun pada Rpm 1000 hingga 1500 lampu menyala dengan terang.

4.2.7 Hasil Pengujian Generator Untuk Pengisian Baterai Akumulator

Jika pada jam 08.00 sampai dengan 17.00 generator dapat berputar dengan kecepatan 700 rpm maka daya yang dihasilkan akan stabil dengan tegangan 14.5 Volt dan daya yang dikeluarkan sebesar 0.9 Ampere. Jika di total daya yang dikeluarkan dari jam 08.00 sampai dengan jam 17.00 yaitu 0.9 x 10 = 9 Ampere

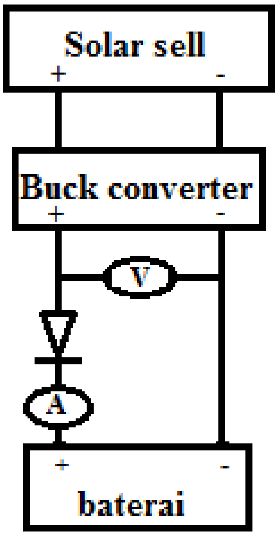
4.3 Pengujian Panel Sel Surya

Pengujian panel sel surya dilakukan dengan dan tanpa beban, untuk melihat pengaruh cahaya dan pengisian serta waktu yang berbeda dalam pengisian baterai akumulator.

4.3.1 Prosedur Pengujian

Pembebanan disini dilakukan langsung ke baterai

1. Pengujian panel sel surya dilakukan tanpa beban dengan mengukur intensitas cahaya matahari dalam rentan waktu satu jam untuk mengetahui tegangan yang dihasilkan.
2. Pengujian panel sel surya dilakukan dengan beban akumulator menggunakan *buck converter* dengan cara merangkai dan menghubungkan panel sel surya dengan alat ukur seperti gambar 4.11 dibawah ini

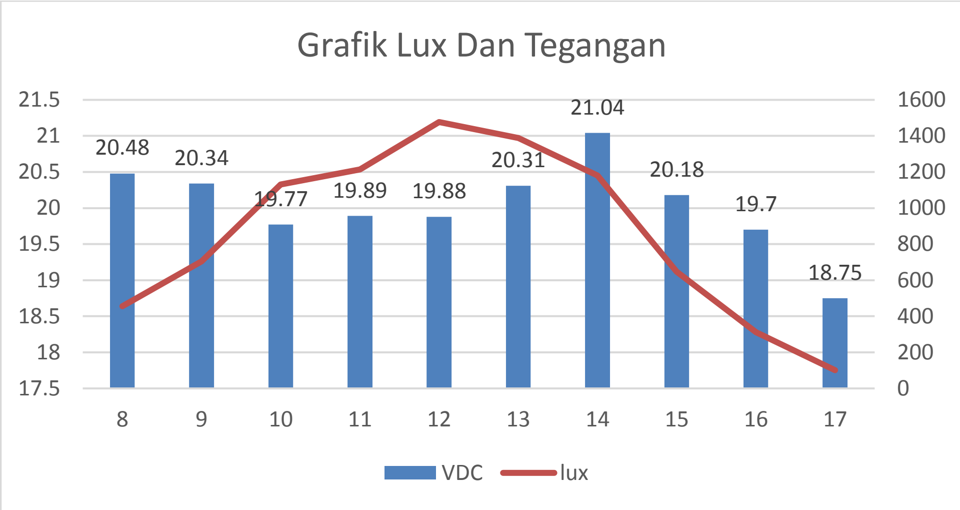


Gambar 4. 11 Blok Diagram Pengujian Panel Sel Surya Untuk Pengisian

4.3.2 Pengujian Panel Sel Surya Tanpa Beban

Tabel 4. 5 Pengujian Panel Sel Surya Tanpa Beban

Tanggal	Jam	Intensitas Cahaya Matahari (Lux)	VDC
21/05/2017	08.00	456	20.48
	09.00	705	20.34
	10.00	1130	19.77
	11.00	1214	19.89
	12.00	1477	19.88
	13.00	1389	20.31
	14.00	1181	21.04
	15.00	648	20.18
	16.00	312	19.70
	17.00	101	18.75



Gambar 4. 12 Grafik Pengujian Panel Sel Surya Tanpa Beban

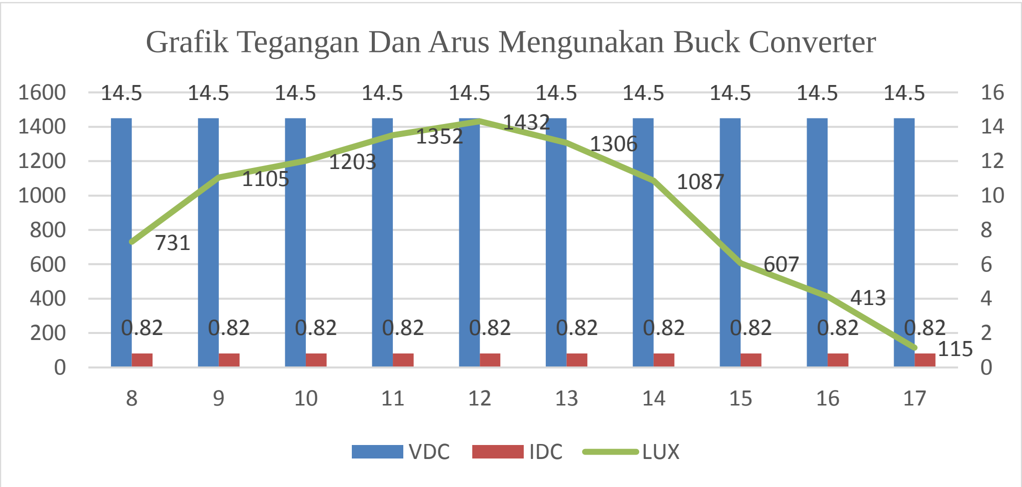
Gambar 4. 13 Gambar Pengujian Panel Sel Surya Tanpa Beban

Pada pengujian panel sel surya tanpa beban di peroleh data intensitas cahaya dan tegangan pada tanggal 21/05/2017, intensitas cahaya paling besar diperoleh pada jam 12.00 yaitu 1477lux dan tegangan paling tinggi diperoleh pada jam 14.00 yaitu 21.04 Volt.

4.3.3 Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator 12V 100Ah Menggunakan Buck Converter

Tabel 4. 6 Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator Menggunakan *Buck Converter*

Tanggal	Jam	Intensitas Cahaya Matahari (Lux)	VDC	IDC
20/05/2017	08.00	731	14.5	0.82
	09.00	1105	14.5	0.82
	10.00	1203	14.5	0.82
	11.00	1352	14.5	0.82
	12.00	1432	14.5	0.82
	13.00	1306	14.5	0.82
	14.00	1087	14.5	0.82
	15.00	607	14.5	0.82
	16.00	413	14.5	0.82
	17.00	115	14.5	0.82



Gambar 4. 14 Grafik Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator Menggunakan *Buck Converter*

Gambar 4. 15 Gambar Pengujian Panel Sel Surya Dengan Beban Baterai Akumulator

Pada pengujian panel sel surya dengan beban akumulator menggunakan *buck converter* tegangan dan arus sudah stabil.

4.3.4 Hasil Pengujian Panel Sel Surya Untuk Pengisian Baterai Akumulator 12V 100Ah Menggunakan Buck Converter

Dari hasil pengujian panel sel surya daya yang dihasilkan akan stabil dengan tegangan 14.5 Volt dan arus sebesar 0.82 Ampere. Jika di total daya yang di keluarkan panel sel surya dari jam 08.00 sampai dengan jam 17.00 yaitu 0.82 x 10 = 8.2 Ampere.

4.4 Hasil Pengujian Kedua Pembangkit Dengan Beban Baterai Akumulator 12V/100Ah Menggunakan Buck boost converter

Tabel 4. 7 Pengujian Kedua Pembangkit Dengan Beban Baterai Akumulator Menggunakan *Buck Boost Converter*

Jam	Solar sell		Generator	
	VDC	IDC	VDC	IDC
08.00	14.5	0.82	14.5	0.9
09.00	14.5	0.82	14.5	0.9
10.00	14.5	0.82	14.5	0.9
11.00	14.5	0.82	14.5	0.9
12.00	14.5	0.82	14.5	0.9
13.00	14.5	0.82	14.5	0.9

14.00	14.5	0.82	14.5	0.9
15.00	14.5	0.82	14.5	0.9
16.00	14.5	0.82	14.5	0.9
17.00	14.5	0.82	14.5	0.9

Dari hasil pengujian kedua pembangkit dengan beban baterai akumulator menggunakan *buck boost converter* diperoleh hasil penggabungan kedua pembangkit yaitu

IDC Panel sel surya 0.82 x 10 = 8.2 Ampere + IDC generator 0.9 x 10 = 9 Ampere = 17.2 Ampere.

Untuk kapasitas perjam yaitu 17.2 : 10 = 1.72 Ah

Maka kedua pembangkit tersebut perjamnya menghasil daya sebesar 1.72 Ah.

P = I total x Volt = 17.2 x 14.5 = 249.4 Watt

BAB V
PENUTUP

5.1 Kesimpulan

Setelah dilakukan perancangan , pengujian, dan analisa sistem, maka dapat disimpulkan beberapa hal yang dapat digunakan untuk perbaikan dan pengembangan selanjutnya, yaitu :

1. Dari hasil pengujian tegangan AC 3 fasa keluaran generator tenaga angin tanpa beban, didapat keluaran dengan putaran terendah RPM 100 sebesar V-ab 0.5 Volt, V-ac 0.7 Volt dan V-bc 0.7 Volt. Dan putaran tertinggi RPM 1500 sebesar V-AB 7.23 Volt, V-AC 6.91 Volt dan V-BC 6.85 Volt.
2. Dari hasil pengujian tegangan DC keluaran generator tenaga angin setelah melewati dioda penyearah tanpa beban, didapat keluaran dengan putaran terendah RPM 100 sebesar 0.13 Volt, dan putaran tertinggi RPM 1500 sebesar 7.44 Volt.
3. DC Booster bekerja pada tegangan 3 V-DC dan dapat mencapai tegangan konstan 14.5 V-DC dengan putaran generator sebesar 700 RPM.
4. Tegangan yang dihasilkan oleh panel sel surya pada pukul 08.00 sebesar 20.48 V-DC dengan lux sebesar 456. Dan pada pukul 17.00 tegangan sebesar 18.75 V-DC dengan lux sebesar 101. Tegangan puncak diperoleh pada pukul 14.00 sebesar 21.04 V-DC dengan lux sebesar 1181
5. Dengan Buck Converter diperoleh tegangan keluaran konstan pada pukul 08.00-17.00 sebesar 14.5 V-DC.
6. Pada percobaan penggabungan kedua pembangkit setelah melalui sistem kontrol untuk pengisian baterai akumulator dalam kurun waktu 10 jam pada pukul 08.00-17.00 menghasilkan daya sebesar 17.2 Ampere, dan perjamnya menghasilkan daya sebesar 1.72 Ah.

   .

5.2 Saran

Pada pembuatan skripsi ini tidak lepas dari berbagai macam kekurangan dan kesalahan baik dari perancangan sistem maupun peralatan yang telah penulis buat, maka dari itu agar sistem dapat menjadi lebih baik maka dapat dikembangkan lebih sempurna, saran dari penulis antara lain sebagai berikut :

1. Perancangan generator diperhitungkan dengan antara banyaknya lilitan, besarnya penampang lilitan, dan kuat medan magnet pada magnet permanen, karena sangat berpengaruh pada tegangan dan daya yang dihasilkan.
2. Untuk penggunaan panel sel surya harus di perhitungkan sesuai dengan kebutuhan atau perencanaan agar dapat memenuhi kapasitas yang di inginkan.

DAFTAR PUSTAKA

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LAMPIRAN

SURAT PERNYATAAN ORISINALITAS

Yang bertanda tangan di bawah ini :

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NIM	: 1312052
Program Studi	: Teknik. Elektro S-1
Konsentrasi	: Teknik Energi Listrik

Dengan ini menyatakan bahwa Skripsi yang saya buat adalah hasil karya sendiri, tidak merupakan plagiasi dari karya orang lain. Dalam Skripsi ini tidak memuat karya orang lain, kecuali dicantumkan sumbernya sesuai dengan ketentuan yang berlaku.

Demikian surat pernyataan ini saya buat, dan apabila di kemudian hari ada pelanggaran atas surat pernyataan ini, saya bersedia menerima sangsinya.

Malang, Agustus 2017

Yang membuat Pernyataan,

METERAI TEMPEL

6000

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Dipertahankan dihadapan Majelis Penguji Skripsi jenjang Strata Satu (S-1) Pada:

Hari : Selasa

Tanggal : 8 Agustus 2017

Dengan Nilai : 83.3 (A)

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No	Materi Perbaikan	Paraf
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Tanggal : 8 Agustus 2017

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Konsentrasi : Teknik Energi Listrik S-1

Judul Skripsi : **RANCANG BANGUN PEMBANGKIT LISTRIK HIBRIDA MENGGUNAKAN KINCIR ANGIN SUMBU VERTIKAL SAVONIUS DAN PANEL SEL SURYA SKALA KECIL**

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1	Penulisan Rumusan Masalah Kalimat No 2	
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MONITORING BIMBINGAN SKRIPSI
SEMESTER GENAP TAHUN AKADEMIK 2016-2017

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Judul Skripsi : Rancang Bangun Pembangkit Listrik Hibrida Menggunakan Kincir Angin Sumbu Vertikal Savonius Dan Panel Sel Surya Skala Kecil

Minggu Ke-	Hari, Tanggal	Waktu Bimbingan	Materi Bimbingan	Paraf
1	6-4-2017	10.00	BAB I Batasan Masalah	
2	13-4-2017	14.00	Penulisan laporan skripsi	
3	22-5-2017	09.00	Data Pengujian Alat	
4	30-5-2017	13.00	Keluaran Pada Generator	
5	5-06-2017	15.00	Perbaikan Format Jurnal	
6	06-06-2017	15.30	Perbaikan Margin Jurnal	
7	07-06-2017	13.40	Perbaikan Dokumentasi Pengujian Alat	
8	08-06-2017	11.30	Pengujian Ulang Pada Alat	
9	15-06-2017	10.30	Pengecatan Sudu Turbin Angin	
10	19-05-2017	13.00	Penggabungan Tabel Pengujian Dan ACC Jurnal	

Malang, 21 Agustus 2017
Dosen Pembimbing I,

Ir. Yusuf Ismail Nakhoda, MT
NIP.Y.1018800189

PROGRAM STUDI TEKNIK ELEKTRO S-1
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI NASIONAL MALANG
Kampus II : Jl. Raya Karanglo Km. 2 Malang

MONITORING BIMBINGAN SKRIPSI
SEMESTER GENAP TAHUN AKADEMIK 2016-2017

Nama Mahasiswa	: Satriyo Eka Wardhana
NIM	: 1312052
Nama Pembimbing	: Ir, Teguh Herbasuki, MT
Judul Skripsi	: Rancang Bangun Pembangkit Listrik Hibrida Menggunakan Kincir Angin Sumbu Vertikal Savonius Dan Panel Sel Surya Skala Kecil

Minggu Ke-	Hari, Tanggal	Waktu Bimbingan	Materi Bimbingan	Paraf
1	6-4-2017		BAB I Batasan Masalah	
2	13-4-2017		Penulisan laporan skripsi	
3	22-5-2017		Data Pengujian Alat	
4	30-5-2017		Keluaran Pada Generator	
5	3-6-2017		Fluks Pada Magnet Generator	
6	13-7-2017		BAB IV Penambahan Pengujian Dengan Beban Lampu	
7	25-7-2017		Penulisan Laporan	

PROGRAM STUDI TEKNIK ELEKTRO S-1
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI NASIONAL MALANG
Kampus II : Jl. Raya Karanglo Km. 2 Malang

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Minggu Ke-	Hari, Tanggal	Waktu Bimbingan	Materi Bimbingan	Paraf
8				
9				
10				
11				
12				
13				
14				

Malang, 2017
Dosen Pembimbing II,

Ir, Teguh Herbasuki, MT
NIP.Y.1038900209

JURUSAN TEKNIK ELEKTRO S-1
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI NASIONAL MALANG

BERITA ACARA SEMINAR PROPOSAL SKRIPSI
PROGRAM STUDI TEKNIK ELEKTRO S1

KONSENTRASI	T. ENERGI LISTRIK S1

1.	Nama Mahasiswa	Satriyo Eka Wardhana			NIM	1312052
2.	Keterangan Pelaksanaan	Tanggal		Waktu		Tempat / Ruang

Spesifikasi Judul (berilah tanda silang) *)

a.	Sistem Tenaga Elektrik	e.	Embbeded System	i.	Sistem Informasi
b.	Konversi Energi	f.	Antar Muka	j.	Jaringan Komputer
c.	Sistem Kendali	g.	Elektronika Telekomunikasi	k.	Web
d.	Tegangan Tinggi	h.	Elektronika Instrumentasi	l.	Algoritma Cerdas

4. Judul Proposal yang diseminarkan Mahasiswa: RANCANG BANGUN PEMBANGKIT LISTRIK TENAGA HIBRIDA SKALA KECIL "ANGIN DENGAN TURBIN ANGIN SUMBU VERTIKAL(TASV) DAN PHOTO VOLTAIC (PV)"

5. Perubahan Judul yang diusulkan oleh Kelompok Dosen Keahlian: ....

6. Catatan : ....

Catatan : ....

7. Persetujuan Judul Skripsi

Disetujui, Dosen Keahlian I	Disetujui, Dosen Keahlian II
Bambang Prio Hartono, ST., MT	Lauhil Hayusman, ST., MT

Disetujui, Calon Dosen Pembimbing

Mengetahui, Ketua Jurusan.	Pembimbing I	Pembimbing II
M. Ibrahim Ashari,ST,MT NIP. P. 1030100358	Ir. Yusuf Ismail Nakhoda, MT	Ir. Teguh Herbasuki, MT

Keterangan :
*) dilingkari a, b, c, ... sesuai dengan bidang keahlian

Form S-3c

INSTITUT TEKNOLOGI NASIONAL MALANG
FAKULTAS TEKNOLOGI INDUSTRI
JURUSAN TEKNIK ELEKTRO

Formulir Perbaikan Ujian Skripsi

Dalam pelaksanaan Ujian Skripsi Janjang Strata 1 Jurusan Teknik Elektro Konsentrasi T. Energi Listrik / T. Elektronika / T.Infokom, maka perlu adanya perbaikan skripsi untuk mahasiswa :

NAMA : SETKIYO EKA W.D
NIM : 13 12 052
Perbaikan meliputi :

- Penulisan Rumusan Masalah kalimat no : 2.
- [illegible] Rumusan Masalah 2 Tujuan .

Malang,

(NI PUTU A)

INSTITUT TEKNOLOGI NASIONAL MALANG
FAKULTAS TEKNOLOGI INDUSTRI
JURUSAN TEKNIK ELEKTRO

Formulir Perbaikan Ujian Skripsi

Dalam pelaksanaan Ujian Skripsi Janjang Strata 1 Jurusan Teknik Elektro Konsentrasi T. Energi Listrik / T. Elektronika / T.Infokom, maka perlu adanya perbaikan skripsi untuk mahasiswa :

NAMA : Satriyo
N I M :
Perbaikan meliputi :

Macam kotoran angin - berapa saronis ?

Malang,

( )

400KHz 60V 4A Switching Current Boost / Buck-Boost / Inverting DC/DC Converter

Features

- Wide 5V to 32V Input Voltage Range
- Positive or Negative Output Voltage Programming with a Single Feedback Pin
- Current Mode Control Provides Excellent Transient Response
- 1.25V reference adjustable version
- Fixed 400KHz Switching Frequency
- Maximum 4A Switching Current
- SW PIN Built in Over Voltage Protection
- Excellent line and load regulation
- EN PIN TTL shutdown capability
- Internal Optimize Power MOSFET
- High efficiency up to 94%
- Built in Frequency Compensation
- Built in Soft-Start Function
- Built in Thermal Shutdown Function
- Built in Current Limit Function
- Available in TO263-5L package

Applications

- EPC / Notebook Car Adapter
- Automotive and Industrial Boost / Buck-Boost / Inverting Converters
- Portable Electronic Equipment

General Description

The XL6009 regulator is a wide input range, current mode, DC/DC converter which is capable of generating either positive or negative output voltages. It can be configured as either a boost, flyback, SEPIC or inverting converter. The XL6009 built in N-channel power MOSFET and fixed frequency oscillator, current-mode architecture results in stable operation over a wide range of supply and output voltages.

The XL6009 regulator is special design for portable electronic equipment applications.

TO263-5L

Figure1. Package Type of XL6009

Pin Configurations

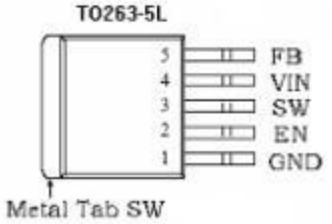


Figure2. Pin Configuration of XL6009 (Top View)

Table 1 Pin Description

Pin Number	Pin Name	Description
1	GND	Ground Pin.
2	EN	Enable Pin. Drive EN pin low to turn off the device, drive it high to turn it on. Floating is default high.
3	SW	Power Switch Output Pin (SW).
4	VIN	Supply Voltage Input Pin. XL6009 operates from a 5V to 32V DC voltage. Bypass Vin to GND with a suitably large capacitor to eliminate noise on the input.
5	FB	Feedback Pin (FB). Through an external resistor divider network, FB senses the output voltage and regulates it. The feedback threshold voltage is 1.25V.

Function Block

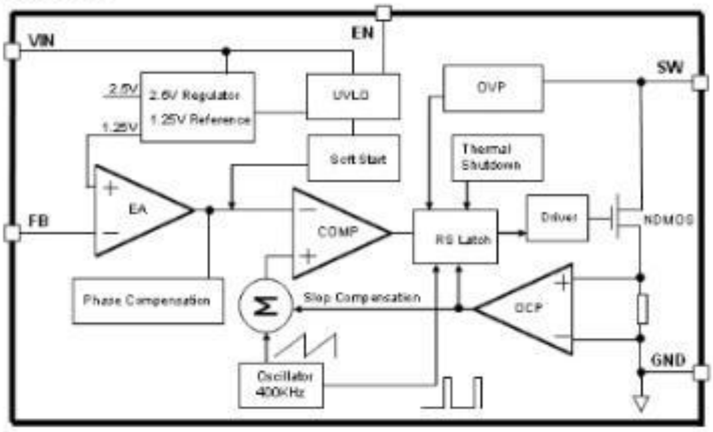


Figure3. Function Block Diagram of XL6009

Typical Application Circuit

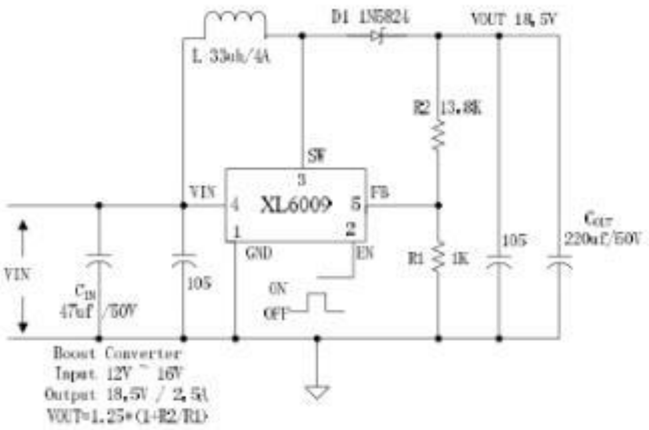


Figure4. XL6009 Typical Application Circuit (Boost Converter)

Ordering Information

Package	Temperature Range	Part Number	Marking ID	Packing Type
		Lead Free	Lead Free	
		XL6009E1	XL6009E1	Tube
		XL6009TRE1	XL6009E1	Tape & Reel

XLSEMI Pb-free products, as designated with "E1" suffix in the par number, are RoHS compliant.

Absolute Maximum Ratings（Note1）

Parameter	Symbol	Value	Unit
Input Voltage	Vin	-0.3 to 36	V
Feedback Pin Voltage	V_{FB}	-0.3 to Vin	V
EN Pin Voltage	V_{EN}	-0.3 to Vin	V
Output Switch Pin Voltage	V_{Output}	-0.3 to 60	V
Power Dissipation	P_D	Internally limited	mW
Thermal Resistance (TO263-5L) (Junction to Ambient, No Heatsink, Free Air)	R_{JA}	30	℃/W
Operating Junction Temperature	T_J	-40 to 125	℃
Storage Temperature	T_{STG}	-65 to 150	℃
Lead Temperature (Soldering, 10 sec)	T_{LEAD}	260	℃
ESD (HBM)		>2000	V

Note1: Stresses greater than those listed under Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operation is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

XL6009 Electrical Characteristics

T_a = 25℃;unless otherwise specified.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
System parameters test circuit figure4						
VFB	Feedback Voltage	Vin = 12V to 16V, Vout=18V Iload=0.1A to 2A	1.213	1.25	1.287	V
Efficiency	ŋ	Vin=12V ,Vout=18.5V Iout=2A	-	92	-	%

Electrical Characteristics (DC Parameters)

Vin = 12V, GND=0V, Vin & GND parallel connect a 220uf/50V capacitor; Iout=0.5A, T_a = 25℃; the others floating unless otherwise specified.

Parameters	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Input operation voltage	Vin		5		32	V
Shutdown Supply Current	I_{STBY}	V_{EN}=0V		70	100	uA
Quiescent Supply Current	I_q	V_{EN} =2V, V_{FB} =Vin		2.5	5	mA
Oscillator Frequency	Fosc		320	400	480	Khz
Switch Current Limit	I_L	V_{FB} =0		4		A
Output Power NMOS	Rdson	Vin=12V, I_{SW}=4A		110	120	mohm
EN Pin Threshold	V_{EN}	High (Regulator ON) Low (Regulator OFF)		1.4 0.8		V
EN Pin Input Leakage Current	I_H	V_{EN} =2V (ON)		3	10	uA
	I_L	V_{EN} =0V (OFF)		3	10	uA
Max. Duty Cycle	D_{MAX}	V_{FB}=0V		90		%

Schottky Diode Selection Table

Current	Surface Mount	Through Hole	VR (The same as system maximum input voltage)				
			20V	30V	40V	50V	60V
1A		√	1N5817	1N5818	1N5819		
3A		√	1N5820	1N5821	1N5822		
		√	MBR320	MBR330	MBR340	MBR350	MBR360
	√		SK32	SK33	SK34	SK35	SK36
	√			30WQ03	30WQ04	30WQ05	
		√		31DQ03	31DQ04	31DQ05	
		√	SR302	SR303	SR304	SR305	SR306
5A		√	1N5823	1N5824	1N5825		
		√	SR502	SR503	SR504	SR505	SR506
		√	SB520	SB530	SB540	SB550	SB560
	√			50WQ03	50WQ04	50WQ05	

Typical System Application for EPC/Notebook Car Adapter – Boost (Output 18.5V/2.5A)

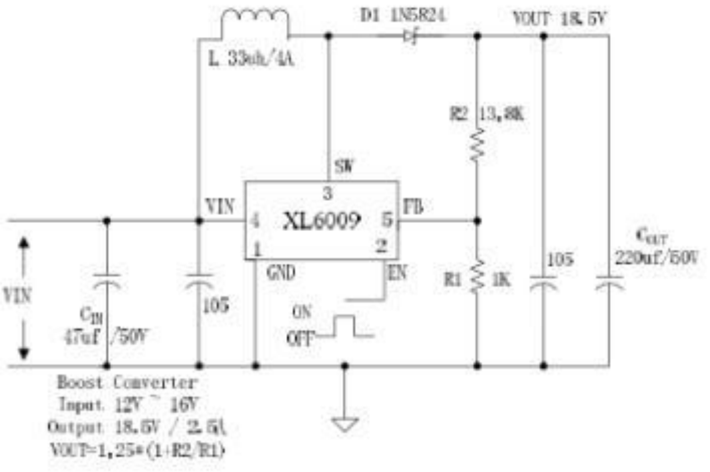


Figure5. XL6009 Typical System Application (Boost Converter)

Typical System Application for Portable Notebook Car Adapter

– SEPIC Buck-Boost Topology (Input 10V~30V, Output 12V/2A)

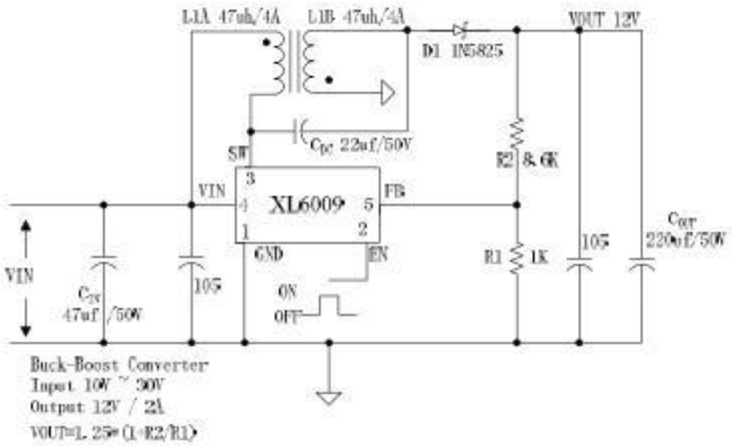


Figure6. XL6009 Typical System Application (SEPIC Buck-Boost Converter)

Typical System Application for Inverting Converter

– SEPIC Inverting Topology (Input 10V~30V, Output + -12V/1A)

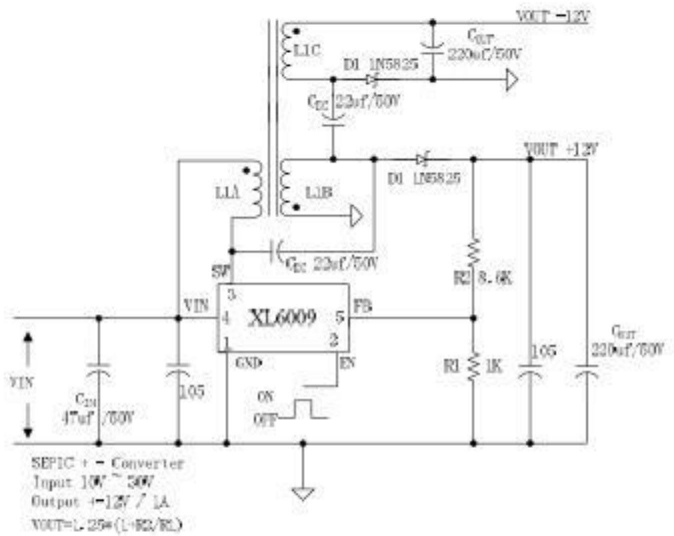
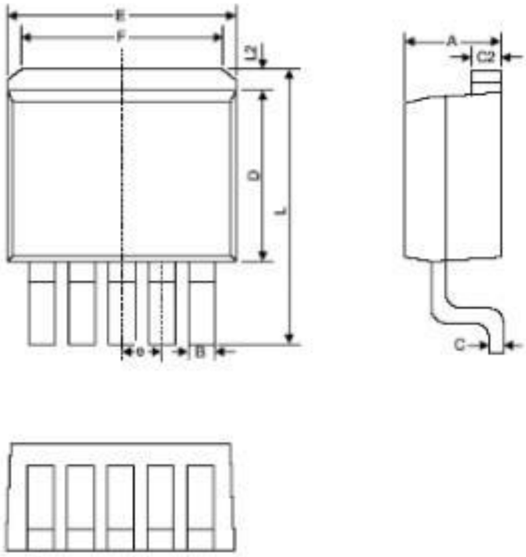


Figure7. XL6009 Typical System Application (SEPIC Inverting Converter)

Package Information

TO263-5L



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	4.440	4.650	0.175	0.183
B	0.710	0.970	0.028	0.038
C	0.360	0.640	0.014	0.025
C2	1.255	1.285	0.049	0.051
D	8.390	8.890	0.330	0.350
E	9.960	10.360	0.392	0.408
e	1.550	1.850	0.061	0.073
F	6.360	7.360	0.250	0.290
L	13.950	14.750	0.549	0.581
L2	1.120	1.420	0.044	0.056

PRELIMINARY
February 1996

LM2596 SIMPLE SWITCHER® Power Converter 150 kHz 3A Step-Down Voltage Regulator

General Description

The LM2596 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation†, and a fixed-frequency oscillator.

The LM2596 series operates at a switching frequency of 150 kHz thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Available in a standard 5-lead TO-220 package with several different lead bend options, and a 5-lead TO-263 surface mount package.

A standard series of inductors are available from several different manufacturers optimized for use with the LM2596 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage under specified input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 80 µA standby current. Self protection features include a two stage frequency reducing current limit for the output switch and an over temperature shutdown for complete protection under fault conditions.

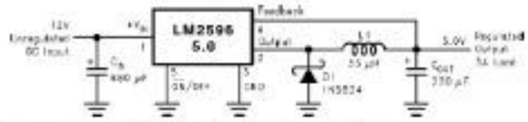
Features

- 3.3V, 5V, 12V, and adjustable output versions
- Adjustable version output voltage range, 1.2V to 37V ±4% max over line and load conditions
- Available in TO-220 and TO-263 packages
- Guaranteed 3A output load current
- Input voltage range up to 40V
- Requires only 4 external components
- Excellent line and load regulation specifications
- 150 kHz fixed frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, I_Q typically 80 µA
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down (buck) regulator
- On-card switching regulators
- Positive to negative converter

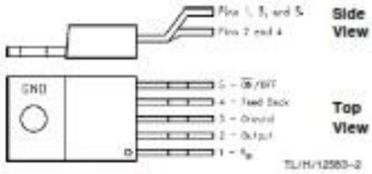
Typical Application (Fixed Output Voltage Versions)



TL/H/12583–1

Connection Diagrams and Ordering Information

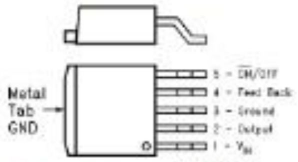
Bent and Staggered Leads, Through Hole Package
5-Lead TO-220 (T)



TL/H/12583–2

Order Number LM2596T-3.3, LM2596T-5.0, LM2596T-12 or LM2596T-ADJ
See NS Package Number T05D

Surface Mount Package
5-Lead TO-263 (S)



TL/H/12583–3

Order Number LM2596S-3.3, LM2596S-5.0, LM2596S-12 or LM2596S-ADJ
See NS Package Number TS5B

†Patent Number 5,382,918.

LM2596 SIMPLE SWITCHER® Power Converter 150 kHz 3A Step-Down Voltage Regulator

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	45V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3 \leq V \leq +25V$
Feedback Pin Voltage	$-0.3 \leq V \leq +25V$
Output Voltage to Ground (Steady State)	$-1V$
Power Dissipation	Internally limited
Storage Temperature Range	$-65°C$ to $+150°C$
ESD Susceptibility	
Human Body Model (Note 2)	2 kV
Lead Temperature	
S Package	
Vapor Phase (60 sec.)	$+215°C$
Infrared (10 sec.)	$+245°C$
T Package (Soldering, 10 sec.)	$+260°C$
Maximum Junction Temperature	$+150°C$

Operating Conditions

Temperature Range	$-40°C \leq T_J \leq +125°C$
Supply Voltage	4.5V to 40V

LM2596-3.3

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2596-3.3 Typ (Note 3)	LM2596-3.3 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$4.75V \leq V_{IN} \leq 40V$, $0.2A \leq I_{LOAD} \leq 3A$	3.3		V
				3.168/**3.135**	V(min)
				3.432/**3.465**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	73		%

LM2596-5.0

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2596-5.0 Typ (Note 3)	LM2596-5.0 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$7V \leq V_{IN} \leq 40V$, $0.2A \leq I_{LOAD} \leq 3A$	5.0		V
				4.800/**4.750**	V(min)
				5.200/**5.250**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	80		%

LM2596-12

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2596-12 Typ (Note 3)	LM2596-12 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$15V \leq V_{IN} \leq 40V$, $0.2A \leq I_{LOAD} \leq 3A$	12.0		V
				11.52/**11.40**	V(min)
				12.48/**12.60**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	90		%

LM2596-ADJ

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2596-ADJ Typ (Note 3)	LM2596-ADJ Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{FB}	Feedback Voltage	$4.5V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 3A$ V_{OUT} programmed for 3V. Circuit of *Figure 2*	1.230	1.193/**1.180** 1.267/**1.280**	V V(min) V(max)
η	Efficiency	$V_{IN} = 12V$, $V_{OUT} = 3V$, $I_{LOAD} = 3A$	73		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version and $V_{IN} = 24V$ for the 12V version. $I_{LOAD} = 500$ mA

Symbol	Parameter	Conditions	LM2596-XX Typ (Note 3)	LM2596-XX Limit (Note 4)	Units (Limits)
DEVICE PARAMETERS					
I_b	Feedback Bias Current	Adjustable Version Only, $V_{FB} = 1.3V$	10	50/**100**	nA nA (max)
f_O	Oscillator Frequency	(Note 6)	150	127/**110** 173/**173**	kHz kHz(min) kHz(max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 3A$ (Notes 7 and 8)	1.16	1.4/**1.5**	V V(max)
DC	Max Duty Cycle (ON) Min Duty Cycle (OFF)	(Note 8) (Note 9)	100 0		%
I_{CL}	Current Limit	Peak Current (Notes 7 and 8)	4.5	3.6/**3.4** 6.9/**7.5**	A A(min) A(max)
I_L	Output Leakage Current	(Notes 7, 9, and 10) Output = 0V Output = −1V	2	50 30	μA(max) mA mA(max)
I_Q	Quiescent Current	(Note 9)	5	10	mA mA(max)
I_{STBY}	Standby Quiescent Current	ON/OFF pin = 5V (OFF) (Note 10)	80	200/**250**	μA μA(max)
θ_{JC} θ_{JA} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	TO-220 or TO-263 Package, Junction to Case TO-220 Package, Junction to Ambient (Note 11) TO-263 Package, Junction to Ambient (Note 12) TO-263 Package, Junction to Ambient (Note 13) TO-263 Package, Junction to Ambient (Note 14)	2 50 50 30 20		°C/W °C/W °C/W °C/W °C/W
ON/OFF CONTROL Test Circuit *Figure 2*					
V_{IH} V_{IL}	$\overline{ON}$/OFF Pin Logic Input Threshold Voltage	Low (Regulator ON) High (Regulator OFF)	1.3	**0.6** **2.0**	V V(max) V(min)
I_H	$\overline{ON}$/OFF Pin Input Current	$V_{LOGIC} = 2.5V$ (Regulator OFF)	5	15	μA μA(max)
I_L		$V_{LOGIC} = 0.5V$ (Regulator ON)	0.02	5	μA μA(max)

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

Note 3: Typical numbers are at 25°C and represent the most likely norm.

Note 4: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).

Note 5: External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2596 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 6: The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.

Note 7: No diode, inductor or capacitor connected to output pin.

Note 8: Feedback pin removed from output and connected to 0V to force the output transistor switch ON.

Note 9: Feedback pin removed from output and connected to 12V for the 3.3V, 5V, and the ADJ. version, and 15V for the 12V version, to force the output transistor switch OFF.

Note 10: V_{IN} = 40V.

Note 11: Junction to ambient thermal resistance (no external heat sink) for the TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately 1 in^2.

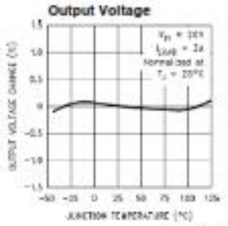
Note 12: Junction to ambient thermal resistance with the TO-263 package tab soldered to a single printed circuit board with 0.5 in^2 of (1 oz.) copper area.

Note 13: Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with 2.5 in^2 of (1 oz.) copper area.

Note 14: Junction to ambient thermal resistance with the TO-263 package tab soldered to a double sided printed circuit board with 3 in^2 of (1 oz.) copper area on the LM2596S side of the board, and approximately 16 in^2 of copper on the other side of the p-c board. See Application Information in this data sheet and the thermal model in ***Switchers Made Simple***® version 4.3 software.

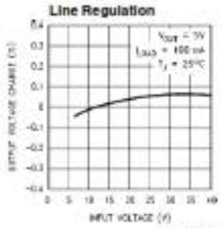
Typical Performance Characteristics (Circuit of *Figure 2*)

Normalized Output Voltage



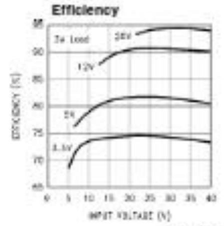
TL/H/12583–4

Line Regulation



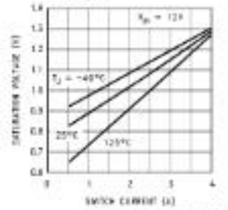
TL/H/12583–5

Efficiency



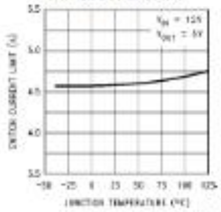
TL/H/12583–6

Switch Saturation Voltage



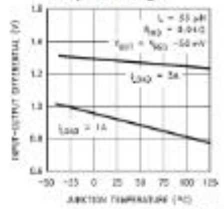
TL/H/12583–7

Switch Current Limit



TL/H/12583–8

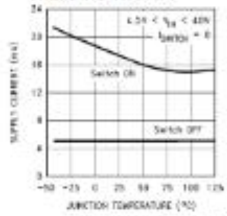
Dropout Voltage



TL/H/12583–9

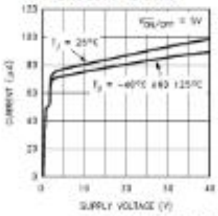
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Operating Quiescent Current



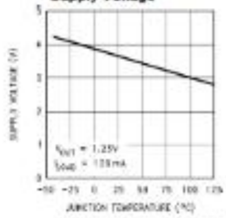
TL/H/12583-10

Shutdown Quiescent Current



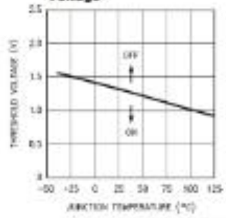
TL/H/12583-11

Minimum Operating Supply Voltage



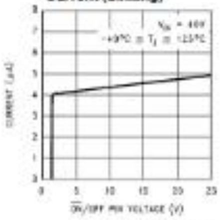
TL/H/12583-12

$\overline{ON}$/OFF Threshold Voltage



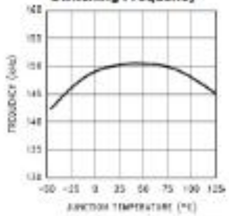
TL/H/12583-13

$\overline{ON}$/OFF Pin Current (Sinking)



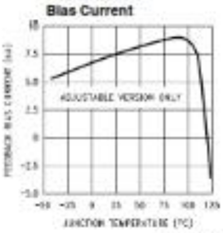
TL/H/12583-14

Switching Frequency



TL/H/12583-15

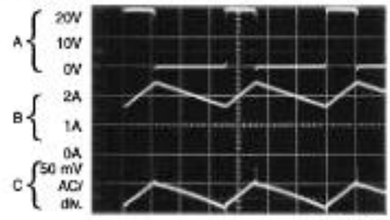
Feedback Pin Bias Current



TL/H/12583-16

Typical Performance Characteristics (Circuit of *Figure 2*)

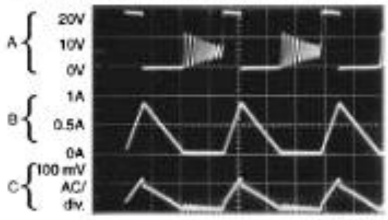
Continuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 2A
L = 32 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



TL/H/12583–17

A: Output Pin Voltage, 10V/div.
B: Inductor Current 1A/div.
C: Output Ripple Voltage, 50 mV/div.
Horizontal Time Base: 2 μs/div.

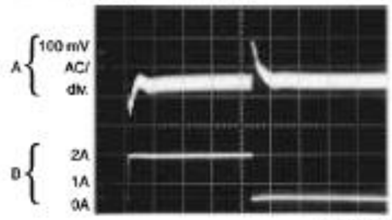
Discontinuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA
L = 10 μH, C_{OUT} = 330 μF, C_{OUT} ESR = 45 mΩ



TL/H/12583–18

A: Output Pin Voltage, 10V/div.
B: Inductor Current 0.5A/div.
C: Output Ripple Voltage, 100 mV/div.
Horizontal Time Base: 2 μs/div.

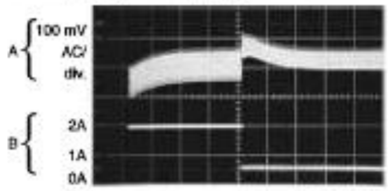
Load Transient Response for Continuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 32 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



TL/H/12583–19

A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse
Horizontal Time Base: 100 μs/div.

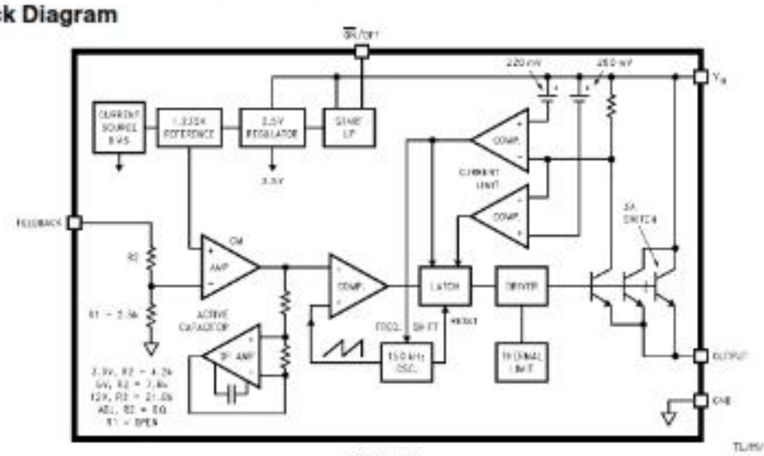
Load Transient Response for Discontinuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 10 μH, C_{OUT} = 330 μF, C_{OUT} ESR = 45 mΩ



TL/H/12583–20

A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse
Horizontal Time Base: 200 μs/div.

Block Diagram

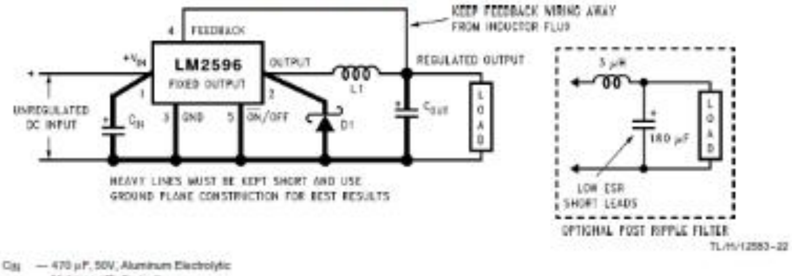


TL/H/12583–21

FIGURE 1

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



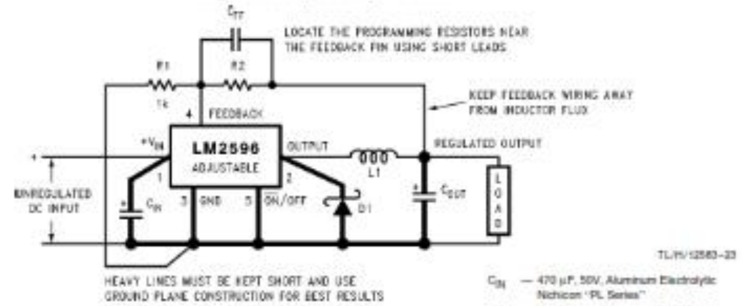
C_{IN} — 470 µF, 50V, Aluminum Electrolytic Nichicon "PL Series"

C_{OUT} — 220 µF, 25V Aluminum Electrolytic, Nichicon "PL Series"

D1 — 5A, 40V Schottky Rectifier, 1N5825

L1 — 68 µH, L38

Adjustable Output Voltage Versions



$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$ where $V_{REF} = 1.23V$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$ Select R_1 to be approximately 1 kΩ, use a 1% resistor for best stability.

C_{IN} — 470 µF, 50V, Aluminum Electrolytic Nichicon "PL Series"

C_{OUT} — 220 µF, 35V Aluminum Electrolytic, Nichicon "PL Series"

D1 — 5A, 40V Schottky Rectifier, 1N5825

L1 — 68 µH, L38

R_1 — 1 kΩ, 1%

C_{FF} — See Application Information Section

FIGURE 2. Standard Test Circuits and Layout Guides

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance can generate voltage transients which can cause problems. For minimal inductance and ground loops, the wires indicated by **heavy lines should be wide printed circuit traces and should be kept as short as possible.** For best results, external components should be located as close to the switcher IC as possible using ground plane construction or single point grounding.

If **open core inductors are used,** special care must be taken as to the location and positioning of this type of inductor. Allowing the inductor flux to intersect sensitive feedback, IC groundpath and C_{OUT} wiring can cause problems.

When using the adjustable version, special care must be taken as to the location of the feedback resistors and the associated wiring. Physically locate both resistors near the IC, and route the wiring away from the inductor, especially an open core type of inductor. (See application section for more information.)

LM2596 Series Buck Regulator Design Procedure (Fixed Output)

PROCEDURE (Fixed Output Voltage Version)

Given:

V_{OUT} = Regulated Output Voltage (3.3V, 5V or 12V)

V_{IN}(max) = Maximum DC Input Voltage

I_{LOAD}(max) = Maximum Load Current

1. Inductor Selection (L1)

A. Select the correct inductor value selection guide from *Figures 5, 6, or 7.* (Output voltages of 3.3V, 5V, or 12V respectively.) For all other voltages, see the design procedure for the adjustable version.

B. From the inductor value selection guide, identify the inductance region intersected by the Maximum Input Voltage line and the Maximum Load Current line. Each region is identified by an inductance value and an inductor code (LXX).

C. Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 9.*

2. Output Capacitor Selection (C_{OUT})

A. In the majority of applications, low ESR (Equivalent Series Resistance) electrolytic capacitors between 82 μF and 820 μF and low ESR solid tantalum capacitors between 10 μF and 470 μF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 820 μF.

For additional information, see section on output capacitors in application information section.

B. To simplify the capacitor selection procedure, refer to the quick design component selection table shown in *Figure 3.* This table contains different input voltages, output voltages, and load currents, and lists various inductors and output capacitors that will provide the best design solutions.

C. The capacitor voltage rating for electrolytic capacitors should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements for low output ripple voltage.

D. For computer aided design software, see ***Switchers Made Simple***® version 4.3 or later.

3. Catch Diode Selection (D1)

A. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2596. The most stressful condition for this diode is an overload or shorted output condition.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

C. This diode must be fast (short reverse recovery time) and must be located close to the LM2596 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-

Procedure continued on next page.

EXAMPLE (Fixed Output Voltage Version)

Given:

V_{OUT} = 5V

V_{IN}(max) = 12V

I_{LOAD}(max) = 3A

1. Inductor Selection (L1)

A. Use the inductor selection guide for the 5V version shown in *Figure 6.*

B. From the inductor value selection guide shown in *Figure 6,* the inductance region intersected by the 12V horizontal line and the 3A vertical line is 33 μH, and the inductor code is L40.

C. The inductance value required is 33 μH. From the table in *Figure 9,* go to the L40 line and choose an inductor part number from any of the four manufacturers shown. (In most instance, both through hole and surface mount inductors are available.)

2. Output Capacitor Selection (C_{OUT})

A. See section on output capacitors in application information section.

B. From the quick design component selection table shown in *Figure 3,* locate the 5V output voltage section. In the load current column, choose the load current line that is closest to the current needed in your application, for this example, use the 3A line. In the maximum input voltage column, select the line that covers the input voltage needed in your application, in this example, use the 15V line. Continuing on this line are recommended inductors and capacitors that will provide the best overall performance.

The capacitor list contains both through hole electrolytic and surface mount tantalum capacitors from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturer's series that are listed in the table be used.

In this example aluminum electrolytic capacitors from several different manufacturers are available with the range of ESR numbers needed.

330 μF 35V Panasonic HFQ Series

330 μF 35V Nichicon PL Series

C. For a 5V output, a capacitor voltage rating at least 7.5V or more is needed. But even a low ESR, switching grade, 220 μF 10V aluminum electrolytic capacitor would exhibit approximately 225 mΩ of ESR (see the curve in *Figure 14* for the ESR vs voltage rating). This amount of ESR would result in relatively high output ripple voltage. To reduce the ripple to 1% of the output voltage, or less, a capacitor with a higher value or with a higher voltage rating (lower ESR) should be selected. A 16V or 25V capacitor will reduce the ripple voltage by approximately half.

3. Catch Diode Selection (D1)

A. Refer to the table shown in *Figure 12.* In this example, a 5A, 20V, 1N5823 Schottky diode will provide the best performance, and will not be overstressed even for a shorted output.

Example continued on next page.

PROCEDURE (Fixed Output Voltage Version)

Efficiency rectifiers also provide good results. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.

4. Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin to prevent large voltage transients from appearing at the input. This capacitor should be located close to the IC using short leads. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

For an aluminum electrolytic, the capacitor voltage rating should be approximately 1.5 times the maximum input voltage. Caution must be exercised if solid tantalum capacitors are used (see Application Information on input capacitor). The tantalum capacitor voltage rating should be 2 times the maximum input voltage and it is recommended that they be surge current tested by the manufacturer.

Use caution when using ceramic capacitors for input bypassing, because it may cause severe ringing at the V_{IN} pin.

For additional information, see section on input capacitors in Application Information section.

EXAMPLE (Fixed Output Voltage Version)

4. Input Capacitor (C_{IN})

The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 12V, an aluminum electrolytic capacitor with a voltage rating greater than 18V (1.5 × V_{IN}) would be needed. The next higher capacitor voltage rating is 25V.

The RMS current rating requirement for the input capacitor in a buck regulator is approximately ½ the DC load current. In this example, with a 3A load, a capacitor with a RMS current rating of at least 1.5A is needed. The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 35V line and note which capacitor values have RMS current ratings greater than 1.5A. A 680 μF/35V capacitor could be used.

For a through hole design, a 680 μF/35V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate.

For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rating (see Application Information on input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

Conditions			Inductor		Output Capacitor			
					Through Hole Electrolytic		Surface Mount Tantalum	
Output Voltage (V)	Load Current (A)	Max Input Voltage (V)	Inductance (μH)	Inductor (#)	Panasonic HFQ Series (μF/V)	Nichicon PL Series (μF/V)	AVX TPS Series (μF/V)	Sprague 595D Series (μF/V)
3.3	3	5	22	L41	470/25	560/16	330/6.3	390/6.3
		7	22	L41	560/35	560/35	330/6.3	390/6.3
		10	22	L41	680/35	680/35	330/6.3	390/6.3
		40	33	L40	560/35	470/35	330/6.3	390/6.3
	2	6	22	L33	470/25	470/35	330/6.3	390/6.3
		10	33	L32	330/35	330/35	330/6.3	390/6.3
		40	47	L39	330/35	270/50	220/10	330/10
5	3	8	22	L41	470/25	560/16	220/10	330/10
		10	22	L41	560/25	560/25	220/10	330/10
		15	33	L40	330/35	330/35	220/10	330/10
		40	47	L39	330/35	270/35	220/10	330/10
	2	9	22	L33	470/25	560/16	220/10	330/10
		20	68	L38	180/35	180/35	100/10	270/10
		40	68	L38	180/35	180/35	100/10	270/10
12	3	15	22	L41	470/25	470/25	100/16	180/16
		18	33	L40	330/25	330/25	100/16	180/16
		30	68	L44	180/25	180/25	100/16	120/20
		40	68	L44	180/35	180/35	100/16	120/20
	2	15	33	L32	330/25	330/25	100/16	180/16
		20	68	L38	180/25	180/25	100/16	120/20
		40	150	L42	82/25	82/25	68/20	68/25

FIGURE 3. LM2596 Fixed Voltage Quick Design Component Selection Table

LM2596 Series Buck Regulator Design Procedure (Adjustable Output)

PROCEDURE (Adjustable Output Voltage Version)

Given:

V_{OUT} = Regulated Output Voltage

$V_{IN}(max)$ = Maximum Input Voltage

$I_{LOAD}(max)$ = Maximum Load Current

F = Switching Frequency *(Fixed at a nominal 150 kHz).*

1. **Programming Output Voltage** (Selecting R_1 and R_2, as shown in *Figure 2*)

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

Select a value for R_1 between 240Ω and 1.5 kΩ. The lower resistor values minimize noise pickup in the sensitive feedback pin. (For the lowest temperature coefficient and the best stability with time, use 1% metal film resistors.)

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. **Inductor Selection (L1)**

A. Calculate the inductor Volt • microsecond constant E • T (V • μs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT} - V_{SAT}) \bullet \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D} \bullet \frac{1000}{150\ kHz} (V \bullet \mu s)$$

where V_{SAT} = internal switch saturation voltage = 1.16V

and V_D = diode forward voltage drop = 0.5V

B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the Inductor Value Selection Guide shown in *Figure 8*.

C. on the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the E • T value and the Maximum Load Current value. Each region is identified by an inductance value and an inductor code (LXX).

E. Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 9*.

3. **Output Capacitor Selection (C_{OUT})**

A. In the majority of applications, low ESR electrolytic or solid tantalum capacitors between 82 μF and 820 μF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 820 μF. **For additional information, see section on output capacitors in application information section.**

B. To simplify the capacitor selection procedure, refer to the quick design table shown in *Figure 4*. This table contains different output voltages, and lists various output capacitors that will provide the best design solutions.

C. The capacitor voltage rating should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements needed for low output ripple voltage.

Procedure continued on next page.

EXAMPLE (Adjustable Output Voltage Version)

Given:

V_{OUT} = 20V

$V_{IN}(max)$ = 28V

$I_{LOAD}(max)$ = 3A

F = Switching Frequency *(Fixed at a nominal 150 kHz).*

1. **Programming Output Voltage** (Selecting R_1 and R_2, as shown in *Figure 2*)

Select R_1 to be 1 kΩ, 1%. Solve for R_2.

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{20V}{1.23V} - 1\right)$$

R_2 = 1k (16.26 − 1) = 15.26k, closest 1% value is 15.4 kΩ.

R_2 = 15.4 kΩ.

2. **Inductor Selection (L1)**

A. Calculate the inductor Volt • microsecond constant (E • T),

$$E \bullet T = (28 - 20 - 1.16) \bullet \frac{20 + 0.5}{28 - 1.16 + 0.5} \bullet \frac{1000}{150} (V \bullet \mu s)$$

$$E \bullet T = (6.84) \bullet \frac{20.5}{27.34} \bullet 6.67\ (V \bullet \mu s) = 34.2\ (V \bullet \mu s)$$

B. E • T = 34.2 (V • μs)

C. $I_{LOAD}(max)$ = 3A

D. From the inductor value selection guide shown in *Figure 8*, the inductance region intersected by the 34 (V • μs) horizontal line and the 3A vertical line is 47 μH, and the inductor code is L39.

E. From the table in *Figure 9*, locate line L39, and select an inductor part number from the list of manufacturers part numbers.

3. **Output Capacitor Selection (C_{OUT})**

A. See section on C_{OUT} in Application Information section.

B. From the quick design table shown in *Figure 4*, locate the output voltage column. From that column, locate the output voltage closest to the output voltage in your application. In this example, select the 24V line. Under the output capacitor section, select a capacitor from the list of through hole electrolytic or surface mount tantalum types from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturers series that are listed in the table be used.

In this example, through hole aluminum electrolytic capacitors from several different manufacturers are available.

220 μF/35V Panasonic HFQ Series

150 μF/35V Nichicon PL Series

Example continued on next page.

LM2596 Series Buck Regulator Design Procedure (Adjustable Output)

PROCEDURE (Adjustable Output Voltage Version)

4. Feedforward Capacitor (C_{FF}) (See *Figure 2*)

For output voltages greater than approximately 10V, an additional capacitor is required. The compensation capacitor is typically between 100 pF and 33 nF, and is wired in parallel with the output voltage setting resistor, R_2. It provides additional stability for high output voltages, low input-output voltages, and/or very low ESR output capacitors, such as solid tantalum capacitors.

$$C_{FF} = \frac{1}{31 \times 10^3 \times R_2}$$

This capacitor type can be ceramic, plastic, silver mica, etc. (Because of the unstable characteristics of ceramic capacitors made with Z5U material, they are not recommended.)

5. Catch Diode Selection (D1)

A. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2596. The most stressful condition for this diode is an overload or shorted output condition.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

C. This diode must be fast (short reverse recovery time) and must be located close to the LM2596 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turn-off characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N4001 series are much too slow and should not be used.

6. Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground to prevent large voltage transients from appearing at the input. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

This capacitor should be located close to the IC using short leads and the voltage rating should be approximately 1.5 times the maximum input voltage.

If solid tantalum input capacitors are used, it is recomended that they be surge current tested by the manufacturer.

Use caution when using a high dielectric constant ceramic capacitor for input bypassing, because it may cause severe ringing at the V_{IN} pin.

For additional information, see section on input capacitors in application information section.

EXAMPLE (Adjustable Output Voltage Version)

C. For a 20V output, a capacitor rating of at least 30V or more is needed. In this example, either a 35V or 50V capacitor would work. A 35V rating was chosen, although a 50V rating could also be used if a lower output ripple voltage is needed.

Other manufacturers or other types of capacitors may also be used, provided the capacitor specifications (especially the 100 kHz ESR) closely match the types listed in the table. Refer to the capacitor manufacturers data sheet for this information.

4. Feedforward Capacitor (C_{FF})

The table shown in *Figure 4* contains feed forward capacitor values for various output voltages. In this example, a 560 pF capacitor is needed.

5. Catch Diode Selection (D1)

A. Refer to the table shown in *Figure 12*. Schottky diodes provide the best performance, and in this example a 5A, 40V, 1N5825 Schottky diode would be a good choice. The 5A diode rating is more than adequate and will not be overstressed even for a shorted output.

6. Input Capacitor (C_{IN})

The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 28V, an aluminum electrolytic aluminum electrolytic capacitor with a voltage rating greater than 42V ($1.5 \times V_{IN}$) would be needed. Since the the next higher capacitor voltage rating is 50V, a 50V capacitor should be used. The capacitor voltage rating of ($1.5 \times V_{IN}$) is a conservative guideline, and can be modified somewhat if desired.

The RMS current rating requirement for the input capacitor of a buck regulator is approximately ½ the DC load current. In this example, with a 3A load, a capacitor with a RMS current rating of at least 1.5A is needed.

The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 50V line and note which capacitor values have RMS current ratings greater than 1.5A. Either a 470 μF or 680 μF, 50V capacitor could be used.

For a through hole design, a 680 μF/50V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. Other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate.

For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rting (see Application Information or input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. ***Switchers Made Simple*** *(version 4.3 or later) is available on a 3½" diskette for IBM compatible computers.*

(Continued)

Output Voltage (V)	Through Hole Output Capacitor			Surface Mount Output Capacitor		
	Panasonic HFQ Series (μF/V)	**Nichicon PL Series (μF/V)**	**Feedforward Capacitor**	**AVX TPS Series (μF/V)**	**Sprague 595D Series (μF/V)**	**Feedforward Capacitor**
2	820/35	820/35	33 nF	330/6.3	470/4	33 nF
4	560/35	470/35	10 nF	330/6.3	390/6.3	10 nF
6	470/25	470/25	3.3 nF	220/10	330/10	3.3 nF
9	330/25	330/25	1.5 nF	100/16	180/16	1.5 nF
12	330/25	330/25	1 nF	100/16	180/16	1 nF
15	220/35	220/35	680 pF	68/20	120/20	680 pF
24	220/35	150/35	560 pF	33/25	33/25	220 pF
28	100/50	100/50	390 pF	10/35	15/50	220 pF

FIGURE 4. Output Capacitor and Feedforward Capacitor Selection Table

LM2596 Series Buck Regulator Design Procedure

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

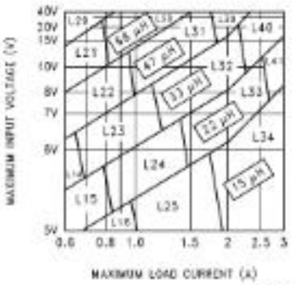


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FIGURE 5. LM2596-3.3

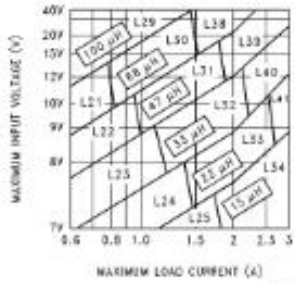

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FIGURE 6. LM2596-5.0

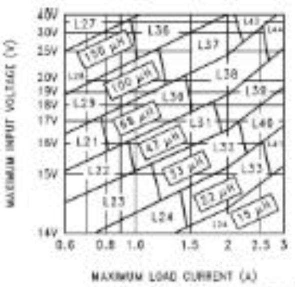

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FIGURE 7. LM2596-12

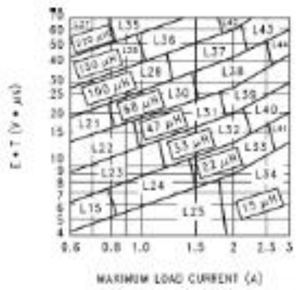

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FIGURE 8. LM2596-ADJ

LM2596 Series Buck Regulator Design Procedure (Continued)

	Inductance (μH)	Current (A)	Schott		Renco		Pulse Engineering		Coilcraft
			Through Hole	Surface Mount	Through Hole	Surface Mount	Through Hole	Surface Mount	Surface Mount
L15	22	0.99	67148350	67148460	RL-1284-22-43	RL1500-22	PE-53815	PE-53815-S	DO3308-223
L21	68	0.99	67144070	67144450	RL-5471-5	RL1500-68	PE-53821	PE-53821-S	DO3316-683
L22	47	1.17	67144080	67144460	RL-5471-6	—	PE-53822	PE-53822-S	DO3316-473
L23	33	1.40	67144090	67144470	RL-5471-7	—	PE-53823	PE-53823-S	DO3316-333
L24	22	1.70	67148370	67148480	RL-1283-22-43	—	PE-53824	PE-53825-S	DO3316-223
L25	15	2.10	67148380	67148490	RL-1283-15-43	—	PE-53825	PE-53824-S	DO3316-153
L26	330	0.80	67144100	67144480	RL-5471-1	—	PE-53826	PE-53826-S	DO5022P-334
L27	220	1.00	67144110	67144490	RL-5471-2	—	PE-53827	PE-53827-S	DO5022P-224
L28	150	1.20	67144120	67144500	RL-5471-3	—	PE-53828	PE-53828-S	DO5022P-154
L29	100	1.47	67144130	67144510	RL-5471-4	—	PE-53829	PE-53829-S	DO5022P-104
L30	68	1.78	67144140	67144520	RL-5471-5	—	PE-53830	PE-53830-S	DO5022P-683
L31	47	2.20	67144150	67144530	RL-5471-6	—	PE-53831	PE-53831-S	DO5022P-473
L32	33	2.50	67144160	67144540	RL-5471-7	—	PE-53932	PE-53932-S	DO5022P-333
L33	22	3.10	67148390	67148500	RL-1283-22-43	—	PE-53933	PE-53933-S	DO5022P-223
L34	15	3.40	67148400	67148790	RL-1283-15-43	—	PE-53934	PE-53934-S	DO5022P-153
L35	220	1.70	67144170	—	RL-5473-1	—	PE-53935	PE-53935-S	—
L36	150	2.10	67144180	—	RL-5473-4	—	PE-54036	PE-54036-S	—
L37	100	2.50	67144190	—	RL-5472-1	—	PE-54037	PE-54037-S	—
L38	68	3.10	67144200	—	RL-5472-2	—	PE-54038	PE-54038-S	—
L39	47	3.50	67144210	—	RL-5472-3	—	PE-54039	PE-54039-S	—
L40	33	3.50	67144220	67148290	RL-5472-4	—	PE-54040	PE-54040-S	—
L41	22	3.50	67144230	67148300	RL-5472-5	—	PE-54041	PE-54041-S	—
L42	150	2.70	67148410	—	RL-5473-4	—	PE-54042	PE-54042-S	—
L43	100	3.40	67144240	—	RL-5473-2	—	PE-54043		—
L44	68	3.40	67144250	—	RL-5473-3	—	PE-54044		—

FIGURE 9. Inductor Manufacturers Part Numbers

Coilcraft Inc.	Phone	(800) 322-2645
	FAX	(708) 639-1469
Coilcraft Inc., Europe	Phone	+11 1236 730 595
	FAX	+44 1236 730 627
Pulse Engineering Inc.	Phone	(619) 674-8100
	FAX	(619) 674-8262
Pulse Engineering Inc., Europe	Phone	+353 93 24 107
	FAX	+353 93 24 459
Renco Electronics Inc.	Phone	(800) 645-5828
	FAX	(516) 586-5562
Schott Corp.	Phone	(612) 475-1173
	FAX	(612) 475-1786

FIGURE 10. Inductor Manufacturers Phone Numbers

Nichicon Corp.	Phone	(708) 843-7500
	FAX	(708) 843-2798
Panasonic	Phone	(714) 373-7857
	FAX	(714) 373-7102
AVX Corp.	Phone	(803) 448-9411
	FAX	(803) 448-1943
Sprague/Vishay	Phone	(207) 324-4140
	FAX	(207) 324-7223

FIGURE 11. Capacitor Manufacturers Phone Numbers

VR	3A Diodes				4A–6A Diodes			
	Surface Mount		Through Hole		Surface Mount		Through Hole	
	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery
20V		All of these diodes are rated to at least 50V.	1N5820	All of these diodes are rated to at least 50V.		All of these diodes are rated to at least 50V.	SR502	All of these diodes are rated to at least 50V.
	SK32		SR302				1N5823	
			MBR320				SB520	
30V	30WQ03		1N5821					
	SK33		MBR330		50WQ03		SR503	
			31DQ03				1N5824	
40V			1N5822				SB530	
	SK34		SR304		50WQ04		SR504	
	MBRS340		MBR340				1N5825	
	30WQ04	MURS320	31DQ04	MUR320		MURS620	SB540	MUR620
50V or More	SK35	30WF10	SR305			50WF10		HER601
	MBRS360		MBR350		50WQ05		SB550	
	30WQ05		31DQ05				50SQ080	

FIGURE 12. Diode Selection Table

Application Information

PIN FUNCTIONS

$+V_{IN}$—This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents needed by the regulator.

Ground—Circuit ground.

Output—Internal switch. The voltage at this pin switches between $(+V_{IN} - V_{SAT})$ and approximately $-0.5V$, with a duty cycle of approximately V_{OUT}/V_{IN}. To minimize coupling to sensitive circuitry, the PC board copper area connected to this pin should be kept to a minimum.

Feedback—Senses the regulated output voltage to complete the feedback loop.

$\overline{ON}$/OFF—Allows the switching regulator circuit to be shut down using logic level signals thus dropping the total input supply current to approximately 80 μA. Pulling this pin below a threshold voltage of approximately 1.3V turns the regulator on, and pulling this pin above 1.3V (up to a maximum of 25V) shuts the regulator down. If this shutdown feature is not needed, the $\overline{ON}$/OFF pin can be wired to the ground pin or it can be left open, in either case the regulator will be in the ON condition.

EXTERNAL COMPONENTS

INPUT CAPACITOR

C_{IN}—A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin. It must be located near the regulator using short leads. This capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous current needed each time the switch turns on.

The important parameters for the input capacitor are the voltage rating and the RMS current rating. Because of the relatively high RMS currents flowing in a buck regulator's input capacitor, this capacitor should be chosen for its RMS current rating rather than its capacitance or voltage ratings, although the capacitance value and voltage rating are directly related to the RMS current rating.

The RMS current rating of a capacitor could be viewed as a capacitor's power rating. The RMS current flowing through the capacitors internal ESR produces power which causes the internal temperature of the capacitor to rise. The RMS current rating of a capacitor is determined by the amount of current required to raise the internal temperature approximately 10°C above an ambient temperature of 105°C. The ability of the capacitor to dissipate this heat to the surrounding air will determine the amount of current the capacitor can safely sustain. Capacitors that are physically large and have a large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating.

The consequences of operating an electrolytic capacitor above the RMS current rating is a shortened operating life. The higher temperature speeds up the evaporation of the capacitor's electrolyte, resulting in eventual failure.

Selecting an input capacitor requires consulting the manufacturers data sheet for maximum allowable RMS ripple current. For a maximum ambient temperature of 40°C, a general guideline would be to select a capacitor with a ripple current rating of approximately 50% of the DC load current. For ambient temperatures up to 70°C, a current rating of 75% of the DC load current would be a good choice for a conservative design. The capacitor voltage rating must be at least 1.25 times greater than the maximum input voltage, and often a much higher voltage capacitor is needed to satisfy the RMS current requirements.

A graph shown in *Figure 13* shows the relationship between an electrolytic capacitor value, its voltage rating, and the RMS current it is rated for. These curves were obtained from the Nichicon "PL" series of low ESR, high reliability electrolytic capacitors designed for switching regulator applications. Other capacitor manufacturers offer similar types of capacitors, but always check the capacitor data sheet.

"Standard" electrolytic capacitors typically have much higher ESR numbers, lower RMS current ratings and typically have a shorter operating lifetime.

Because of their small size and excellent performance, surface mount solid tantalum capacitors are often used for input bypassing, but several precautions must be observed. A small percentage of solid tantalum capacitors can short if the inrush current rating is exceeded. This can happen at turn on when the input voltage is suddenly applied, and of course, higher input voltages produce higher inrush currents. Several capacitor manufacturers do a 100% surge current testing on their products to minimize this potential problem. If high turn on currents are expected, it may be necessary to limit this current by adding either some resistance or inductance before the tantalum capacitor, or select a higher voltage capacitor. As with aluminum electrolytic capacitors, the RMS ripple current rating must be sized to the load current.

FEEDFORWARD CAPACITOR

(Adjustable Output Voltage Version)

C_{FF}—A Feedforward Capacitor C_{FF}, shown across R2 in *Figure 2* is used when the ouput voltage is greater than 10V or when C_{OUT} has a very low ESR. This capacitor adds lead compensation to the feedback loop and increases the phase margin for better loop stability. For C_{FF} selection, see the design procedure section.

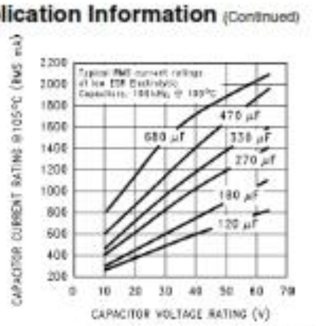

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FIGURE 13. RMS Current Ratings for Low ESR Electrolytic Capacitors (Typical)

OUTPUT CAPACITOR

C_{OUT}—An output capacitor is required to filter the output and provide regulator loop stability. Low impedance or low ESR Electrolytic or solid tantalum capacitors designed for switching regulator applications must be used. When selecting an output capacitor, the important capacitor parameters are; the 100 kHz Equivalent Series Resistance (ESR), the RMS ripple current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter.

The output capacitor requires an ESR value that has an upper and lower limit. For low output ripple voltage, a low ESR value is needed. This value is determined by the maximum allowable output ripple voltage, typically 1% to 2% of the output voltage. But if the selected capacitor's ESR is extremely low, there is a possibility of an unstable feedback loop, resulting in an oscillation at the output. Using the capacitors listed in the tables, or similar types, will provide design solutions under all conditions.

If very low output ripple voltage (less than 15 mV) is required, refer to the section on Output Voltage Ripple and Transients for a post ripple filter.

An aluminum electrolytic capacitor's ESR value is related to the capacitance value and its voltage rating. In most cases, higher voltage electrolytic capacitors have lower ESR values (see *Figure 14*). Often, capacitors with much higher voltage ratings may be needed to provide the low ESR values required for low output ripple voltage.

The output capacitor for many different switcher designs often can be satisfied with only three or four different capacitor values and several different voltage ratings. See the quick design component selection tables in *Figures 3* and *4* for typical capacitor values, voltage ratings, and manufacturers capacitor types.

Electrolytic capacitors are not recommended for temperatures below −25°C. The ESR rises dramatically at cold temperatures and typically rises 3X @ −25°C and as much as 10X at −40°C. See curve shown in *Figure 15*.

Solid tantalum capacitors have a much better ESR spec for cold temperatures and are recommended for temperatures below −25°C.

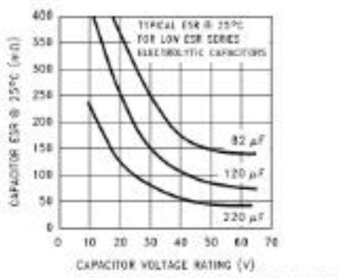

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FIGURE 14. Capacitor ESR vs Capacitor Voltage Rating (Typical Low ESR Electrolytic Capacitor)

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch turns off. This must be a fast diode and must be located close to the LM2596 using short leads and short printed circuit traces.

Because of their very fast switching speed and low forward voltage drop, Schottky diodes provide the best performance, especially in low output voltage applications (5V and lower). Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.

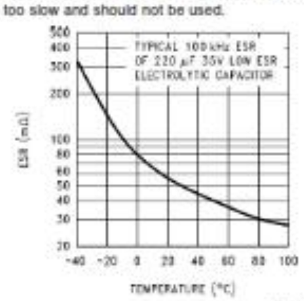

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FIGURE 15. Capacitor ESR Change vs Temperature

INDUCTOR SELECTION

All switching regulators have two basic modes of operation; continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulators performance and requirements. Most switcher designs will operate in the discontinuous mode when the load current is low.

The LM2596 (or any of the Simple Switcher family) can be used for both continuous or discontinuous modes of operation.

Application Information (Continued)

In many cases the preferred mode of operation is the continuous mode. It offers greater output power, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. But it does require larger inductor values to keep the inductor current flowing continuously, especially at low output load currents and/or high input voltages.

To simplify the inductor selection process, an inductor selection guide (nomograph) was designed (see *Figures 5* through *8*). This guide assumes that the regulator is operating in the continuous mode, and selects an inductor that will allow a peak-to-peak inductor ripple current to be a certain percentage of the maximum design load current. This peak-to-peak inductor ripple current percentage is not fixed, but is allowed to change as different design load currents are selected. (See *Figure 16*.)

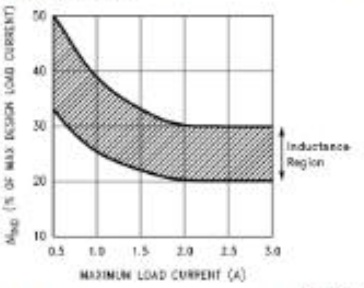

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FIGURE 16. (ΔI_{IND}) Peak-to-Peak Inductor Ripple Current (as a Percentage of the Load Current) vs Load Current

By allowing the percentage of inductor ripple current to increase for low load currents, the inductor value and size can be kept relatively low.

When operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage), with the average value of this current waveform equal to the DC output load current.

Inductors are available in different styles such as pot core, toroid, E-core, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin, rod or stick core, consists of wire wound on a ferrite bobbin. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more Electro-Magnetic Interference (EMI). This magnetic flux can induce voltages into nearby printed circuit traces, thus causing problems with both the switching regulator operation and nearby sensitive circuitry, and can give incorrect scope readings because of induced voltages in the scope probe. Also see section on Open Core Inductors.

When multiple switching regulators are located on the same PC board, open core magnetics can cause interference between two or more of the regulator circuits, especially at high currents. A torroid or E-core inductor (closed magnetic structure) should be used in these situations.

The inductors listed in the selection chart include ferrite E-core construction for Schott, ferrite bobbin core for Renco and Coilcraft, and powdered iron toroid for Pulse Engineering.

Exceeding an inductor's maximum current rating may cause the inductor to overheat because of the copper wire losses, or the core may saturate. If the inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the switch current to rise very rapidly and force the switch into a cycle-by-cycle current limit, thus reducing the DC output load current. This can also result in overheating of the inductor and/or the LM2596. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

DISCONTINUOUS MODE OPERATION

The selection guide chooses inductor values suitable for continuous mode operation, but for low current applications and/or high input voltages, a discontinuous mode design may be a better choice. It would use an inductor that would be physically smaller, and would need only one half to one third the inductance value needed for a continuous mode design. The peak switch and inductor currents will be higher in a discontinuous design, but at these low load currents (1A and below), the maximum switch current will still be less than the switch current limit.

Discontinuous operation can have voltage waveforms that are considerable different than a continuous design. The output pin (switch) waveform can have some damped sinusoidal ringing present. (See *Figure 1* photo titled; Discontinuous Mode Switching Waveforms) This ringing is normal for discontinuous operation, and is not caused by feedback loop instabilities. In discontinuous operation, there is a period of time where neither the switch or the diode are conducting, and the inductor current has dropped to zero. During this time, a small amount of energy can circulate between the inductor and the switch/diode parasitic capacitance causing this characteristic ringing. Normally this ringing is not a problem, unless the amplitude becomes great enough to exceed the input voltage, and even then, there is very little energy present to cause damage.

Different inductor types and/or core materials produce different amounts of this characteristic ringing. Ferrite core inductors have very little core loss and therefore produce the most ringing. The higher core loss of powdered iron inductors produce less ringing. If desired, a series RC could be placed in parallel with the inductor to dampen the ringing. The computer aided design software ***Switchers Made Simple*** (version 4.3) will provide all component values for continuous and discontinuous modes of operation.

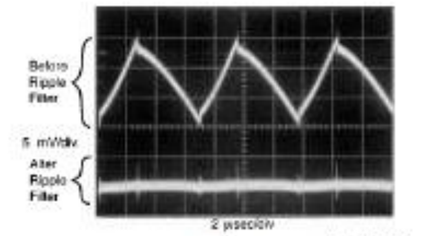

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FIGURE 17. Post Ripple Filter Waveform

Application Information (Continued)

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply operating in the continuous mode will contain a sawtooth ripple voltage at the switcher frequency, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is a function of the inductor sawtooth ripple current and the ESR of the output capacitor. A typical output ripple voltage can range from approximately 0.5% to 3% of the output voltage. To obtain low ripple voltage, the ESR of the output capacitor must be low, however, caution must be exercised when using extremely low ESR capacitors because they can affect the loop stability, resulting in oscillation problems. If very low output ripple voltage is needed (less than 20 mV), a post ripple filter is recommended. (See *Figure 2*.) The inductance required is typically between 1 μH and 5 μH, with low DC resistance, to maintain good load regulation. A low ESR output filter capacitor is also required to assure good dynamic load response and ripple reduction. The ESR of this capacitor may be as low as desired, because it is out of the regulator feedback loop. The photo shown in *Figure 17* shows a typical output ripple voltage, with and without a post ripple filter.

When observing output ripple with a scope, it is essential that a short, low inductance scope probe ground connection be used. Most scope probe manufacturers provide a special probe terminator which is soldered onto the regulator board, preferable at the output capacitor. This provides a very short scope ground thus eliminating the problems associated with the 3 inch ground lead normally provided with the probe, and provides a much cleaner and more accurate picture of the ripple voltage waveform.

The voltage spikes are caused by the fast switching action of the output switch and the diode, and the parasitic inductance of the output filter capacitor, and its associated wiring. To minimize these voltage spikes, the output capacitor should be designed for switching regulator applications, and the lead lengths must be kept very short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

When a switching regulator is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current increases or decreases, the entire sawtooth current waveform also rises and falls. The average value (or the center) of this current waveform is equal to the DC load current.

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will smoothly change from a continuous to a discontinuous mode of operation. Most switcher designs (irregardless how large the inductor value is) will be forced to run discontinuous if the output is lightly loaded. This is a perfectly acceptable mode of operation.

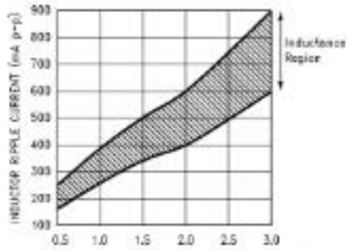

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FIGURE 18. Peak-to-Peak Inductor Ripple Current vs Load Current

In a switching regulator design, knowing the value of the peak-to-peak inductor ripple current (ΔI_{IND}) can be useful for determining a number of other circuit parameters. Parameters such as, peak inductor or peak switch current, minimum load current before the circuit becomes discontinuous, output ripple voltage and output capacitor ESR can all be calculated from the peak-to-peak ΔI_{IND}. When the inductor nomographs shown in *Figures 5* through *8* are used to select an inductor value, the peak-to-peak inductor ripple current can immediately be determined. The curve shown in *Figure 18* shows the range of (ΔI_{IND}) that can be expected for different load currents. The curve also shows how the peak-to-peak inductor ripple current (ΔI_{IND}) changes as you go from the lower border to the upper border (for a given load current) within an inductance region. The upper border represents a higher input voltage, while the lower border represents a lower input voltage (see Inductor Selection Guides).

These curves are only correct for continuous mode operation, and only if the inductor selection guides are used to select the inductor value

Consider the following example:

V_{OUT} = 5V, maximum load current of 2.5A

V_{IN} = 12V, nominal, varying between 10V and 16V.

The selection guide in *Figure 6* shows that the vertical line for a 2.5A load current, and the horizontal line for the 12V input voltage intersect approximately midway between the upper and lower borders of the 33 μH inductance region. A 33 μH inductor will allow a peak-to-peak inductor current (ΔI_{IND}) to flow that will be a percentage of the maximum load current. Referring to *Figure 18*, follow the 2.5A line approximately midway into the inductance region, and read the peak-to-peak inductor ripple current (ΔI_{IND}) on the left hand axis (approximately 620 mA p-p).

As the input voltage increases to 16V, it approaches the upper border of the inductance region, and the inductor ripple current increases. Referring to the curve in *Figure 18*, it can be seen that for a load current of 2.5A, the peak-to-peak inductor ripple current (ΔI_{IND}) is 620 mA with 12V in, and can range from 740 mA at the upper border (16V in) to 500 mA at the lower border (10V in).

Application Information (Continued)

Once the ΔI_{IND} value is known, the following formulas can be used to calculate additional information about the switching regulator circuit.

1. Peak inductor or peak switch current

$$= \left(I_{LOAD} + \frac{\Delta I_{IND}}{2}\right) = \left(2.5A + \frac{0.62}{2}\right) = 2.81A$$

2. Minimum load current before the circuit becomes discontinuous

$$= \frac{\Delta I_{IND}}{2} = \frac{0.62}{2} = 0.31A$$

3. Output Ripple Voltage $= (\Delta I_{IND}) \times (\text{ESR of } C_{OUT})$

$$= 0.62A \times 0.1\Omega = 62 \text{ mV p-p}$$

or

4. ESR of C_{OUT}

$$= \frac{\text{Output Ripple Voltage } (\Delta V_{OUT})}{\Delta I_{IND}}$$

$$= \frac{0.062V}{0.62A} = 0.1\Omega$$

OPEN CORE INDUCTORS

Another possible source of increased output ripple voltage or unstable operation is from an open core inductor. Ferrite bobbin or stick inductors have magnetic lines of flux flowing through the air from one end of the bobbin to the other end. These magnetic lines of flux will induce a voltage into any wire or PC board copper trace that comes within the inductor's magnetic field. The strength of the magnetic field, the orientation and location of the PC copper trace to the magnetic field, and the distance between the copper trace and the inductor, determine the amount of voltage generated in the copper trace. Another way of looking at this inductive coupling is to consider the PC board copper trace as one turn of a transformer (secondary) with the inductor winding as the primary. Many millivolts can be generated in a copper trace located near an open core inductor which can cause stability problems or high output ripple voltage problems.

If unstable operation is seen, and an open core inductor is used, it's possible that the location of the inductor with respect to other PC traces may be the problem. To determine if this is the problem, temporarily raise the inductor away from the board by several inches and then check circuit operation. If the circuit now operates correctly, then the magnetic flux from the open core inductor is causing the problem. Substituting a closed core inductor such as a torroid or E-core will correct the problem, or re-arranging the PC layout may be necessary. Magnetic flux cutting the IC device ground trace, feedback trace, or the positive or negative traces of the output capacitor should be minimized.

Sometimes, locating a trace directly beneath a bobbin inductor will provide good results, provided it is exactly in the center of the inductor (because the induced voltages cancel themselves out), but if it is off center one direction or the other, then problems could arise. If flux problems are present, even the direction of the inductor winding can make a difference in some circuits.

This discussion on open core inductors is not to frighten the user, but to alert the user on what kind of problems to watch out for when using them. Open core bobbin or "stick" inductors are an inexpensive, simple way of making a compact efficient inductor, and they are used by the millions in many different applications.

THERMAL CONSIDERATIONS

The LM2596 is available in two packages, a 5-pin TO-220 (T) and a 5-pin surface mount TO-263 (S).

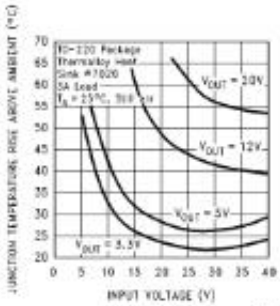
The TO-220 package needs a heat sink under most conditions. The size of the heatsink depends on the input voltage, the output voltage, the load current and the ambient temperature. The curves in *Figure 19* show the LM2596T junction temperature rises above ambient temperature for a 3A load and different input and output voltages. The data for these curves was taken with the LM2596T (TO-220 package) operating as a buck switching regulator in an ambient temperature of 25°C (still air). These temperature rise numbers are all approximate and there are many factors that can affect these temperatures. Higher ambient temperatures require more heat sinking.

The TO-263 surface mount package tab is designed to be soldered to the copper on a printed circuit board. The copper and the board are the heat sink for this package and the other heat producing components, such as the catch diode and inductor. The PC board copper area that the package is soldered to should be at least 0.4 in^2, and ideally should have 2 or more square inches of 2 oz. (0.0028) in) copper. Additional copper area improves the thermal characteristics, but with copper areas greater than approximately 6 in^2, only small improvements in heat dissipation are realized. If further thermal improvements are needed, double sided, multilayer PC board with large copper areas and/or airflow are recommended.

The curves shown in *Figure 20* show the LM2596S (TO-263 package) junction temperature rise above ambient temperature with a 2A load for various input and output voltages. This data was taken with the circuit operating as a buck switching regulator with all components mounted on a PC board to simulate the junction temperature under actual operating conditions. This curve can be used for a quick check for the approximate junction temperature for various conditions, but be aware that there are many factors that can affect the junction temperature. When load currents higher than 2A are used, double sided or multilayer PC boards with large copper areas and/or airflow might be needed, especially for high ambient temperatures and high output voltages.

For the best thermal performance, wide copper traces and generous amounts of printed circuit board copper should be used in the board layout. (One exception to this is the output (switch) pin, which should **not** have large areas of copper.) Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and moving air lowers the thermal resistance even further.

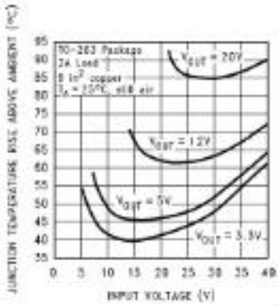
Package thermal resistance and junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers. Some of these factors include board size, shape, thickness, position, location, and even board temperature. Other factors are, trace width, total printed circuit copper area, copper thickness, single- or double-sided, multilayer board and the amount of solder on the board. The effectiveness of the PC board to dissipate heat also depends on the size, quantity and spacing of other components on the board, as well as whether the surrounding air is still or moving. Furthermore, some of these components such as the catch diode will add heat to the PC board and the heat can vary as the input voltage changes. For the inductor, depending on the physical size, type of core material and the DC resistance, it could either act as a heat sink taking heat away from the board, or it could add heat to the board.



TL/H/12583-34

Circuit Data for Temperature Rise Curve TO-220 Package (T)	
Capacitors	Through hole electrolytic
Inductor	Through hole, Renco
Diode	Through hole, 5A 40V, Schottky
PC board	3 square inches single sided 2 oz. copper (0.0028")

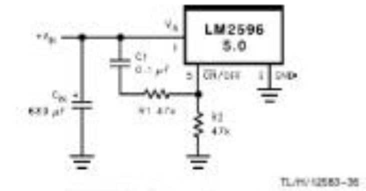
FIGURE 19. Junction Temperature Rise, TO-220



TL/H/12583-35

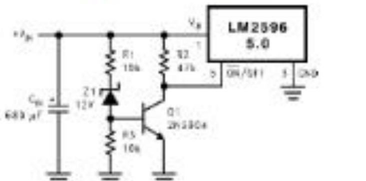
Circuit Data for Temperature Rise Curve TO-263 Package (S)	
Capacitors	Surface mount tantalum, molded "D" size
Inductor	Surface mount, Pulse Engineering, 68 µH
Diode	Surface mount, 5A 40V, Schottky
PC board	9 square inches single sided 2 oz. copper (0.0028")

FIGURE 20. Junction Temperature Rise, TO-263



TL/H/12583-36

FIGURE 21. Delayed Startup



TL/H/12583-37

FIGURE 22. Undervoltage Lockout for Buck Regulator

DELAYED STARTUP

The circuit in *Figure 21* uses the the $\overline{ON}$/OFF pin to provide a time delay between the time the input voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start up is shown). As the input voltage rises, the charging of capacitor C1 pulls the $\overline{ON}$/OFF pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, and resistor R_2 pulls the $\overline{ON}$/OFF pin low, thus allowing the circuit to start switching. Resistor R_1 is included to limit the maximum voltage applied to the $\overline{ON}$/OFF pin (maximum of 25V), reduces power supply noise sensitivity, and also limits the capacitor, C1, discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the $\overline{ON}$/OFF pin and cause problems.

This delayed startup feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

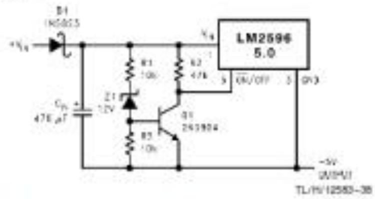
UNDERVOLTAGE LOCKOUT

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. An undervoltage lockout feature applied to a buck regulator is shown in *Figure 22*, while *Figures 23* and *24* applies the same feature to an inverting circuit. The circuit in *Figure 23* features a constant threshold voltage for turn on and turn off (zener voltage plus approximately one volt). If hysteresis is needed, the circuit in *Figure 24* has a turn ON voltage which is different than the turn OFF voltage. The amount of hysteresis is approximately equal to the value of the output voltage. If zener voltages greater than 25V are used, an additional 47 kΩ resistor is needed from the $\overline{ON}$/OFF pin to the ground pin to stay within the 25V maximum limit of the $\overline{ON}$/OFF pin.

Application Information (Continued)

INVERTING REGULATOR

The circuit in *Figure 25* converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the regulator's ground pin to the negative output voltage, then grounding the feedback pin, the regulator senses the inverted output voltage and regulates it.



TL/H/12583–38

This circuit has an ON/OFF threshold of approximately 13V.

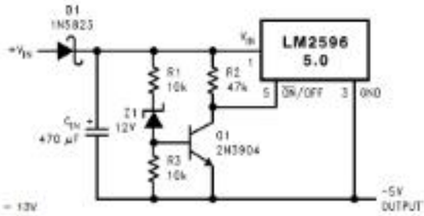
FIGURE 23. Undervoltage Lockout for Inverting Regulator

This example uses the LM2596-5.0 to generate a −5V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version. Since this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. The curve shown in *Figure 26* provides a guide as to the amount of output load current possible for the different input and output voltage conditions.

The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 40V. For example, when converting +20V to −12V, the regulator would see 32V between the input pin and ground pin. The LM2596 has a maximum input voltage spec of 40V.

Additional diodes are required in this regulator configuration. Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closley resemble a buck configuration thus providing good closed loop stability. A Schottky diode is recommended for low input voltages, (because of its lower voltage drop) but for higher input voltages, a fast recovery diode could be used.

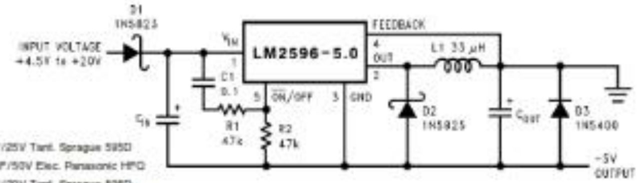
Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.



This circuit has hysteresis
Regulator starts switching at V_{IN} = 13V
Regulator stops switching at V_{IN} = 8V

TL/H/12583–39

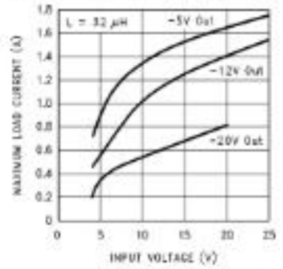
FIGURE 24. Undervoltage Lockout with Hysteresis for Inverting Regulator



C_{IN} — 68 µF/25V Tant. Sprague 595D
470 µF/50V Elec. Panasonic HFQ
C_{OUT} — 47 µF/20V Tant. Sprague 595D
220 µF/25V Elec. Panasonic HFQ

TL/H/12583–40

FIGURE 25. Inverting −5V Regulator with Delayed Startup



TL/H/12583–41

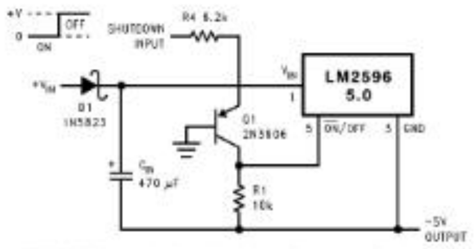
FIGURE 26. Inverting Regulator Typical Load Current

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 33 μH, 3.5A inductor is the best choice. Capacitor selection can also be narrowed down to just a few values. Using the values shown in *Figure 25* will provide good results in the majority of inverting designs.

This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the LM2596 current limit (approx 4.5A) are needed for at least 2 ms or more, until the output reaches its nominal output voltage. The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, may not work correctly. Because of the relatively high startup currents required by the inverting topology, the delayed startup feature (C1, R_1 and R_2) shown in *Figure 25* is recommended. By delaying the regulator startup, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current needed for startup is now supplied by the input capacitor (C_{IN}). For severe start up conditions, the input capacitor can be made much larger than normal.

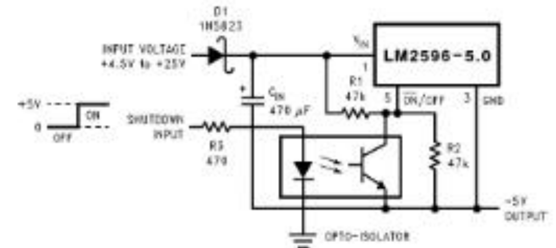
INVERTING REGULATOR SHUTDOWN METHODS

To use the $\overline{\text{ON}}$/OFF pin in a standard buck configuration is simple, pull it below 1.3V (@25°C, referenced to ground) to turn regulator ON, pull it above 1.3V to shut the regulator OFF. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in *Figures 27* and *28*.



TL/H/12583–42

FIGURE 27. Inverting Regulator Ground Referenced Shutdown

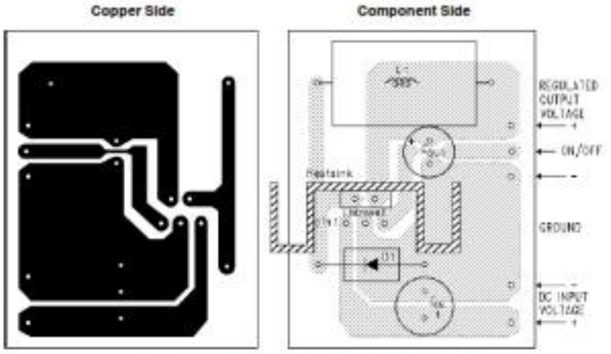


TL/H/12583–43

FIGURE 28. Inverting Regulator Ground Referenced Shutdown using Opto Device

Application Information (Continued)

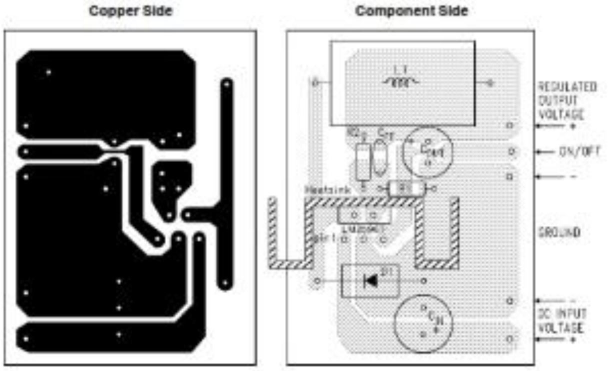
TYPICAL THROUGH HOLE PC BOARD LAYOUT, FIXED OUTPUT (1X SIZE), DOUBLE SIDED



TL/H/12583-44

C_{IN} —470 μF, 50V, Aluminum Electrolytic Panasonic, "HFQ Series"
C_{OUT} —330 μF, 35V, Aluminum Electrolytic Panasonic, "HFQ Series"
D1 —5A, 40V Schottky Rectifier, 1N5825
L1 —47 μH, L39, Renco, Through Hole
Thermalloy Heat Sink #7020

TYPICAL THROUGH HOLE PC BOARD LAYOUT, ADJUSTABLE OUTPUT (1X SIZE), DOUBLE SIDED

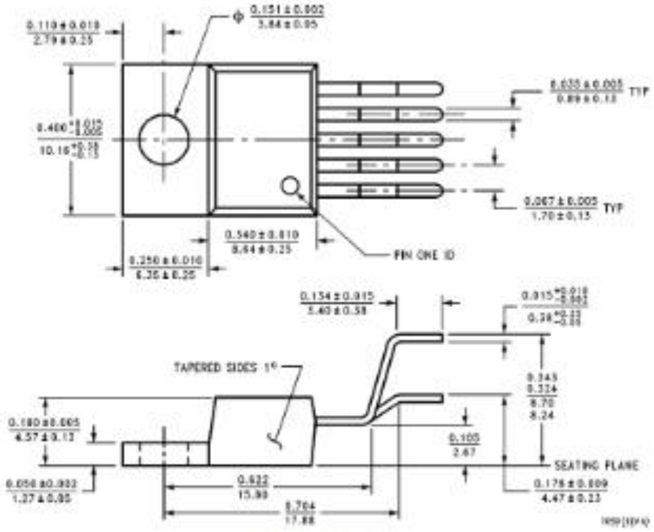


TL/H/12583-45

C_{IN} —470 μF, 50V, Aluminum Electrolytic Panasonic, "HFQ Series"
C_{OUT} —220 μF, 35V Aluminum Electrolytic Panasonic, "HFQ Series"
D1 —5A, 40V Schottky Rectifier, 1N5825
L1 —47 μH, L39, Renco, Through Hole
R_1 —1 kΩ, 1%
R_2 —Use formula in Design Procedure
C_{FF} —See *Figure 4*.
Thermalloy Heat Sink #7020

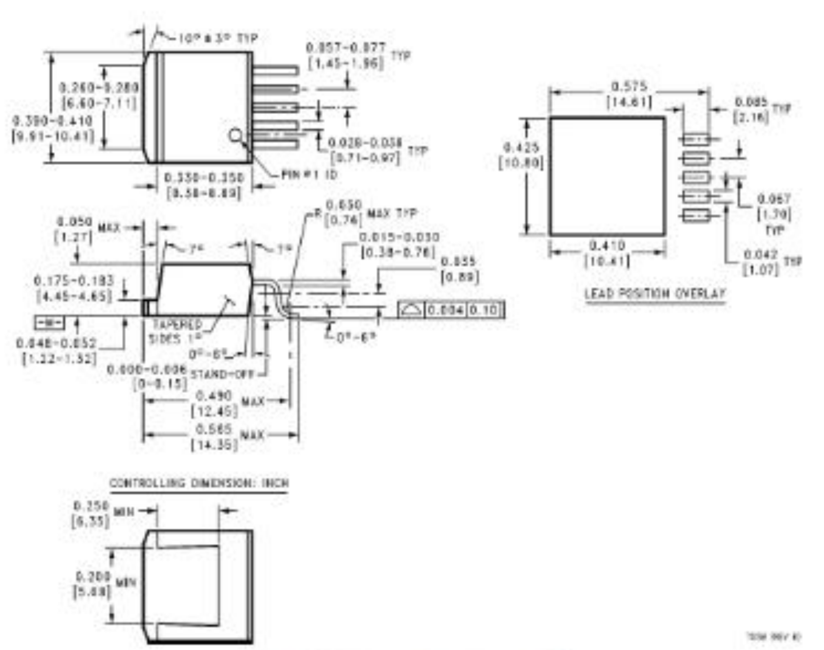
FIGURE 29. PC Board Layout

Physical Dimensions inches (millimeters)



5-Lead TO-220 (T)
Order Number LM2596T-3.3, LM2596T-5.0,
LM2596T-12 or LM2596T-ADJ
NS Package Number T05D

Physical Dimensions inches (millimeters) (Continued)



5-Lead TO-263 Surface Mount Package (S)
Order Number LM2596S-3.3, LM2596S-5.0, LM2596S-12 or LM2596S-ADJ
NS Package Number TS5B

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